Report NASA CR-72289

260-SL-3 MOTOR PROGRAM

FINAL REPORT

Contract NAS3-7998

31 July 1967

Prepared for

National Aeronautics and Space Administration
NASA Lewis Research Center
Cleveland, Ohio

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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FOREWORD

This report provides a summary of work performed in the design, fabrication, and test firing of a 260-in.-dia, short-length motor designated Motor 260-SL-3. All work was performed under National Aeronautics and Space Administration Contract NAS3-7998 during the period 10 March 1966 through 30 June 1967. The full-duration static firing of Motor 260-SL-3 on 17 June 1967 provided a further demonstration of the feasibility of large solid-propellant rocket motors.

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I. SUMMARY

The basic objective of the 260-SL-3 Motor Program was to design, fabricate, and statically test fire a short-length 260-in.-dia solid rocket motor. The program was established to be consistent with the general NASA program goal of maintaining the 260-in.-dia motor processing capability through June 1967. Specific objectives of the program were:

A. To verify the design concepts and fabrication techniques selected for large ablative nozzles using a submerged nozzle configuration similar to that proposed for use with thrust vector control systems.

B. To demonstrate, in a polybutadiene propellant formulation suitable for 260-in.-dia motors, the attainment of a propellant burning rate of approximately 0.7/in./sec at 600 psia.

C. To further confirm the suitability of materials, component designs, fabrication techniques, and processing procedures selected for use in large solid rocket motors and to further demonstrate the predictability and reproducibility of component performance.

D. To demonstrate the capability to control motor thrust characteristics during tailoff by use of inert slivers.

The test firing of Motor 260-SL-3 on 17 June 1967 resulted in the following significant accomplishments:

A. The predicted propellant burning rate of about 0.73 in./sec at 600 psia was obtained.

B. Performance of the nozzle demonstrated adequacy of the submerged design and of ablative component material and fabrication process selections.

C. The feasibility of rehabilitation and reuse of motor pressure vessel and insulation components enabling minimum cost fabrication of static test motors was demonstrated.

D. The feasibility of installation of a conductive rubber burnthrough sensor and its functionality at motor operating conditions was demonstrated.

E. Capability was demonstrated to achieve reliable motor ignition with an aft end mounted igniter for an additional range of motor ignition parameters.

The program was conducted in accordance with a detailed program plan[(1)*] prepared by Aerojet-General Corporation. All program elements were completed within the scope of effort and in compliance with overall scheduling as shown by this program plan.

II. PREVIOUS EFFORT UNDER CONTRACT NAS3-6284

The 260-in.-dia motor feasibility demonstration program was initiated in June 1963 under the technical direction of the Air Force Rocket Propulsion Laboratory. The program represented a logical advancement of the development of large solid rocket motors from previous 100, 120, and 156-in.-dia motors tested. Program management was transferred to the National Aeronautics and Space Administration Lewis Research Center in March 1965 and subsequent effort was completed under Contract NAS3-6284. A summary of all program effort and accomplishments is provided in the Final Program Summary Report for that contract.[(2)] The successful test firing of two 260-in.-dia motors (260-SL-1[(3)] and 260-SL-2[(4)]) in this program constituted a major milestone in solid rocket technology. The two successful tests demonstrated that state-of-the-art materials and fabrication processes could be applied to produce motors of this unprecedented size.

Major elements of the motor design demonstrated in these two test firings were:

* Superscripts refer to references listed in Section VIII.

A. Adequacy of design and fabrication of a high performance pressure vessel using 18% nickel maraging steel cold formed and welded plate sections and rolled ring forgings was demonstrated. All components were joined by welding using the downhand tungsten inert gas welding technique. The design of the pressure vessel was derived from that of a full-length motor and all fabrication processes required for the full-length chamber were demonstrated in the short length chambers fabricated.

B. An insulation design for all pressure vessel components using premolded and secondarily bonded sections of Gen-Gard V-44 rubber material was demonstrated. Again, the materials and processes are completely applicable to larger motors.

C. The nozzle ablative inserts were fabricated of carbon and silica cloths impregnated with phenolic resin. All components were fabricated by tape wrapping and cure cycles were accomplished in existing pressure vessel facilities. Since the exit cone was too large to be cured in existing facilities, it was cured using a nylon tension overwrap; this process can be applied to much larger size expansion cones. The materials and fabrication processes are applicable to the larger throat size nozzles required for full-length motors.

D. The composite propellant formulation based on a binder system with terpolymer of polybutadiene, acrylic acid, and acrilonitrile was selected for use because of the low raw material cost and the capability to meet mechanical property, ballistic property, and safety requirements. A grain design which demonstrated thrust time characteristics compatible with conventional booster requirements was selected. A liner system was developed which achieved bonding strengths between the propellant and chamber well in excess of calculated loads. Propellant casting was accomplished through a tube with the lower end submerged in the propellant. The low cost formulation, conventional grain design, and simple casting technique produced a homogeneous propellant grain which, in motors test fired, burned almost exactly as predicted.

E. The demonstration of a casting core design capable of being removed as an integral unit without special extraction procedures (that is, not requiring that it be dissolved by solvents or collapsed) and without physical damage to the grain, represented a significant program accomplishment.

F. The aft end ignition system was developed and demonstrated to provide predictable and reproducible ignition for a large propellant grain.

Accomplishments in this first phase, that is the initial Feasibility Demonstration Program, provided the basis on which the 260-SL-3 Motor Program was defined as a logical next step toward the development of a large solid rocket motor for application as a booster in large payload space vehicles.

III. MOTOR CONFIGURATION

Motor 260-SL-3 was designed to enable maximum evaluation of component performance at minimum cost. The basic configuration of the motor is shown by Aerojet Drawing 1005100, Figure 1. Following is a summary of significant design features of each major element of the motor.

A. CHAMBER

Design of Motor 260-SL-3 was based on use of existing pressure vessel components. The chamber selected was the first (SN 001) 260-in.-dia chamber fabricated in the 260-in.-dia Motor Feasibility Demonstration Program and fired in Motor 260-SL-1. Figure 2 shows the basic configuration of this chamber; the design is fully defined by Aerojet Drawing 600252. No structural modifications were made for use of this chamber in Motor 260-SL-3.

B. NOZZLE AND EXIT CONE

Since a basic objective of this program was to test nozzle components sized for the full-length 260-in.-dia motor, a throat diameter of 89.1-in. was specified. Further, since current proposals for nozzles incorporating thrust vector control capability are submerged designs, a similar configuration was required for Motor 260-SL-3. To minimize nozzle fabrication cost without impairing capability to evaluate nozzle component performance, the expansion cone size, the same as previous 260-in.-dia motors, was selected. This results in a 3.8:1 expansion ratio for the specified 89.1-in. throat diameter. While this expansion ratio is lower than optimum value for motor sea level operating conditions, the reduction in maximum thrust resulting from the under-expansion is only 1.2%.

The configuration of the nozzle and exit cone is shown in Aerojet Drawing 1005001, Figure 3. The entrance contour is a 3:2 elliptical shape with a major semi-axis of 3/4 of the throat radius and a 2.0 area ratio at the nose station. The 17.5-degree expansion cone half-angle is tangent to an arc of one throat radius starting at the throat station.

Design was based on using the same nozzle ablative materials used in Motors 260-SL-1 and -2. Phenolic resin impregnated carbon cloth (Fiberite MX 4926) was used on the nozzle ablation surface from the outside of the entrance nose section to a 2.5 area ratio in the exit cone. Phenolic resin impregnated silica cloth (U.S. Polymeric Corp. FM-5131) was used on the ablation surface of the outside portion of the submerged entrance and in the exit cone downstream of the 2.5 area ratio. This latter material was also used as the parallel-to-surface overwrap to provide insulation and structural support for all ablative liner components. The nozzle plastic component thicknesses were determined by scaling the recession rate and using char depths measured from nozzle components used in Motor 260-SL-1. A safety factor was applied to the predicted surface recession, and the total thickness required for ablative liner components was established with the constraint that the 100-degree isotherm be inside the overwrap. The safety factor applied to surface recession depth was variable as a function of the reliability with which prior test results could be applied to predicting performance of this nozzle configuration; thus a factor of 3.0 was used at the nose station, 2.0 at the throat station, and 1.5 for the exit cone liner.

The nozzle shell was designed to incorporate a salvaged section of the 260-SL-1 nozzle shell, P/N 600259, and a new rolled-ring forging. The section salvaged included the forward nozzle attach flange and conical section up to about 114-in. dia. The new forged part included the throat section and exit flange. The entrance ring was designed as a ring-roll forged cantilevered structure supported from the nozzle shell by a bolted joint. The exit cone structural shell consisted of forward and aft steel flange rings and an outer wrap of epoxy impregnated glass roving and cloth in a 65:35 ratio of roving-to-cloth. The insulation, sealants, and adhesives used in the nozzle and exit cone are identical to those previously demonstrated in 260-SL-1 and -2 nozzles, except for a trowelable insulation applied over the Gen-Gard V-44 rubber insulation in the nozzle submerged cavity. This trowelable insulation, IBT-100, provided a final shape similar to the configuration of an omnivector movable nozzle enabling evaluation of erosion characteristics for this configuration.

C. PROPELLANT AND GRAIN DESIGN

The grain design selected for this motor was the same as previous 260-in.-dia motors to permit use of the same casting core. Maximum motor operating pressure was restricted by the limitations of the existing pressure vessel components used. Motor design was predicated on attainment of the maximum allowable operating pressure so that nozzle component performance could be evaluated at an operating pressure as close as possible to that of the 260-SL motor. A propellant burning rate of about 0.71 in./sec at 600 psia was therefore specified which resulted in maximum pressure of about 600 psia. The propellant formulation consisted of the composite formulation based on a binder system of terpolymer of polybutadiene, acrylic acid, and acrylonitrile used in previous 260-in.-dia motors and designated ANB-3105, with minimum modifications necessary to achieve the target burn rate. Prior laboratory work performed by Aerojet had indicated that the target burn rate value could be achieved by relatively modest quantities of additives, without variation of the basic propellant formulation. Attainment of the target burn rate value thus would provide demonstration of capability to utilize the same basic formulation over a wide range of burning rate values.

Inert slivers were included to demonstrate that a predictable effect could be obtained in thrust/time characteristics during motor tailoff. Size of the slivers for Motor 260-SL-3 was based on a solid motor thrust tailoff study conducted by NASA, Lewis Research Center. For the selected sliver weight of about 12,000 lb, a configuration was designed that provided initial exposure at 92 sec burning duration, and by 100 sec, eliminated more than 80% of the burning surface that would otherwise exist. A castable polybutadiene-based insulation material previously developed by Aerojet was selected for the slivers to afford maximum compatibility with the propellant/liner bonding system.

D. INSULATION

The chamber internal insulation configuration was similar to that of Motor 260-SL-1; the design was described in the Insulation Phase Report [(5)]. Minimum insulation thickness requirements were calculated as the product of predicted thickness loss rate and exposure time multiplied by a 2.0 safety factor. Since the useable residual insulation thickness of 0.95 to 1.05 in. in the chamber forward head exceeded the 0.9 in. required minimum thickness, these components were reused. Similarly, since the chamber aft head insulation was eroded only on the aft end immediately adjacent to the step joint, the residual material thickness was well in excess of minimum required for Motor 260-SL-3. To assure a high thickness margin and prevent surface flow discontinuity, the eroded edge was built up to the original thickness with V-61 insulation material.

Design configuration of the cylindrical section insulation consisted of a single ply of 0.2 in. thick autoclave cured V-44 rubber. The longitudinal and circumferential V groove joints between sheets were filled with V-61 potting insulation. The Gen-Gard V-45 forward and aft propellant boots were identical to those previously used in Motors 260-SL-1 and -2, and joints between boot segments were seamed with Germax-cure-accelerated V-45 stock.

E. IGNITION SYSTEM

Configuration of the aft end ignition motor assembly was identical to that used for Motors 260-SL-1 and -2 (Figure 4). The Ladish D-6ac pressure vessel was designed to withstand an internal pressure of 3000 psia, which is twice the maximum expected operating pressure (MEOP = 1500 psia). The propellant grain configuration was an internal burning 30-tooth gear with a nominal 0.50 in. thick web. The propellant was ANP-2758 Mod 1, a polyurethane formulation with a 0.8 in./sec burning rate at 1000 psia.

The ignition motor booster was a modified Polaris B-3 first-stage igniter containing a main charge of 1478 grams of Alclo-iron pyrotechnic material. The safety-and-arming device was the standardized KR 80000-07 unit which is used for each of the three stages of the Minuteman missile.

IV. PROGRAM PLAN

The Program Plan[1] prepared by Aerojet-General Corporation provided the detailed definition of tasks to be performed in the fabrication and static test firing of Motor 260-SL-3. In planning the program, major guidelines applied were:

A. Maintain a high level of quality and performance reliability consistent with that achieved in prior 260-in.-dia motor demonstration firings.

B. Selected materials and processes must have previously been demonstrated to be adequate for conditions encountered in this motor application.

C. Use tooling, materials, and motor components residual from Contract NAS3-6284 to the maximum extent possible.

Program work was planned so that the level of effort was minimal and as nearly constant as possible over the duration of the program. Thus, a minimum stable work force was required and it was possible to maintain a cadre of personnel with maximum competency in all phases of program management, engineering, and fabrication of large solid rocket motors. Actual schedule of accomplishment of major segments of program work is shown by the Major Milestones chart (Figure 5). The following summary of work performed is presented in sequence consistent with the format of this milestone chart.

A. CHAMBER PROCESSING

In preparation of the S/N 001 chamber for use in Motor 260-SL-3, an initial task was to evaluate the degree of structural damage resulting from post-test heat soak after 260-SL-1 motor firing. Test specimens were prepared duplicating the conditions of exterior paint discoloration observed on the chamber and indicated that the maximum exposure temperature was about 425°F. Existing data indicated that such temperatures would not affect metallurgical characteristics of the 18% nickel maraging steel. Additionally, hardness checks of both interior and exterior surfaces indicated no hardness deviations.

The residual rubber insulation was removed from the chamber cylindrical section and the surface was grit blasted. Since numerous small indications of possible corrosion were observed on the chamber exterior, all unmachined exterior surfaces were also grit blasted. A thorough inspection for physical damage revealed no anomalies. Magnetic particle inspection of both interior and exterior surfaces of the cylinder section longitudinal welds and of selected areas of fabrication discrepancies showed no evidence of defects. Ultrasonic and radiographic inspection of cylindrical section longitudinal welds revealed one defect that had not been recorded in previous inspections. The defect was interpreted as a weld porosity, but showed no evidence of propagation of previously accepted weld indications.

After application of primer to both interior and exterior chamber surfaces, chamber structural integrity was verified by a hydrostatic proof test to 706 psig. The test was conducted in the Cast, Cure, and Test Facility at Aerojet Dade-Division using leased portable pumping equipment to pressurize the chamber (Figure 6). This procedure minimized program cost by eliminating the necessity to transport the chamber to and from the existing test facility at Sun Shipbuilding and Dry Dock Co., Chester, Pennsylvania. Strain measurements during the proof test were in excellent agreement with calculated values; all test data and analysis of results were included in the hydrostatic test report[6].

B. CHAMBER INSULATION FABRICATION AND INSTALLATION

Manufacture of the cylindrical section insulation, propellant boots, aft boot extension, forward insulation joint doubler, and firing cap insulation was accomplished by Goodyear Tire and Rubber Company using the same fabrication techniques that were used for components of Motors 260-SL-1 and -2. Sheet stock used for the cylindrical section was fabricated in strips 0.200 in. thick by 32.5 in. wide. The forward and aft propellant boots were fabricated by laying up unvulcanized V-44 stock directly on a released mandrel surface.

Installation of Motor 260-SL-3 insulation components was accomplished by Aerojet personnel at Aerojet-Dade Division. Damaged areas in the residual forward and aft head insulation components were removed and repaired with V-44 strips bonded with Epon 948.2 epoxy resin adhesive. The interior surface of the resulting laminated insulator was buffed to obtain smooth contours. Since a major portion of one insulation segment had been removed from the aft head, a complete replacement segment was bonded in place.

The 0.2-in.-thick strips of V-44 sheet stock were installed in the cylindrical section by hand applying epoxy adhesive, inverting, and rolling to assure that air was removed and full contact of the adhesive was obtained (Figure 7). Twenty-four longitudinal strips, each 32.5 in. wide were installed and a final strip, trimmed to fit the remaining area, was then bonded in place.

All residual V-61 material was removed from the V-groove joints between segments of forward and aft head insulation and these joints, as well as joints between the newly-installed cylindrical section insulation strips, were filled with V-61 potting insulation.

Edges of the forward and aft boot segments were bonded in the respective heads with epoxy adhesive. Joints between segments were seamed with Germax cure-accelerated Gen-Gard V-45 stock. After hand stitching of the stock, the seam was cured by localized heating. The premolded aft boot extension was joined to the boot by bonding with epoxy adhesive. The extension was then assembled to the propellant casting adapter.

The inert slivers were fabricated at A-DD. Process trials, including preparation of 30 lb batches of castable insulation material (designated IBC-101) had previously been conducted at Sacramento. Plywood molds were fabricated to configuration such that each sliver could be cast in six separate segments. The IBC-101 was mixed in 2500 lb batches using the propellant vertical batch mixers at A-DD. A total of six batches were required for the three slivers. All segments cured normally were stripped from the molds without difficulty and were bonded to the chamber cylindrical section insulation with epoxy adhesive. Figure 8 shows one of the slivers installed in the chamber.

C. PROPELLANT EVALUATION AND MOTOR LOADING

A six month propellant tailoring program was conducted at Sacramento followed by scale-up to A-DD production mixers to obtain an early assessment of the full-scale processing characteristics of the modified propellant. This early scale-up program permitted solution of an unexpected cure problem without compromise of the Lot 4 raw material qualification and motor casting schedule.

The tailoring program included small scale (1-, 10-, and 60-lb) propellant mixes to evaluate the effects of burning rate and processability of:

(1) burning rate additive type and quantity, (2) oxidizer particle size distribution including tri- and bimodal blends, and (3) utilization of a ballistically active plasticizer. The ballistically active plasticizer did not prove to be a practical method of increasing burning rate since it caused an unacceptable increase in propellant viscosity. It was found that the target burning rate could be achieved using a mixture of the burning rate additives Iron Blue and BRA-101 with a bimodal oxidizer blend of 55/45 slow speed Mikro pulverized/Mikro atomized. With increased plasticizer levels the processability of these formulations were marginal, having not only higher viscosity than ANB-3105, but "Bingham plastic" flow characteristics which contributed to casting defects and other non-homogeneities.

The processing characteristics of the modified propellant were substantially improved by eliminating the dodecenylsuccinic anhydride from the propellant binder. Interactions between the anhydride and the moisture-containing burning rate additives apparently caused the observed high viscosities and non-Newtonian flow characteristics. The lower viscosity, anhydride-free, formulation permitted an increase in the burning rate additive content (to 0.90 wt% total) and a corresponding decrease in the Mikro atomizer ground portion of the oxidizer blend (to 35 wt%) to yield a propellant which had the required burning rate with apparently acceptable processing characteristics. To reach a steady state of cure within the desired 20 to 30 days, a cure catalyst was included in the formulation. This propellant, designated ANB-3254, was selected for the initial scale-up at A-DD.

A total of ten 5500-lb vertical batch mixes of ANB-3254 propellant were prepared at A-DD during the first scale-up program. Propellant processed at A-DD had two differences from the propellant of identical composition prepared at Sacramento; (1) the burning rate of the A-DD propellant was low, requiring an increase in burning rate additive concentration from 0.90 to 1.30 wt%, and (2) none of the A-DD batches reached a satisfactory state of cure within 20 to 30 days.

Additional vertical mix batches of ANB-3254 were prepared at A-DD with increased levels of the cure catalyst. Several of these batches showed rapid initial cure rates but stabilized at a level under the target 500 psi modulus. Concurrently with the second scale-up program at A-DD, work was being conducted at Sacramento to define the cause of this anomalous cure behavior. It was confirmed that the cure catalyst which was added to the propellant in the premix was being degraded by moisture brought into the premix by the burning rate additives. An alternate method of cure catalyst addition was developed whereby the catalyst was added in solution with the di-epoxide curing agent.

To confirm this alternate method, six vertical batch mixes were prepared at A-DD using a combination of three cure catalyst concentrations and four curing agent levels. All batches cured as expected and a formulation based on 0.032 wt% cure catalyst and 130 equivalents of curing agent was selected for processing in the Lot 4 Raw Material Qualification program at A-DD.

The purposes of the raw material qualification program were to: (1) confirm the propellant formulation selected for casting into Motor 260-SL-3, and (2) evaluate the effects on propellant burning rate of using oxidizer from two sources. Burning rate data from six vertical batch mixes indicated no significant difference in burning rates between propellants prepared with the two types of oxidizer. Long-term cure data from these batches and the pre-qualification batches resulted in a final selection of a formulation containing 0.032 wt% cure catalyst and 125 equivalents of curing agent for casting in Motor 260-SL-3. Satisfactory propellant processing characteristics were demonstrated in the casting of a 44-in.-dia motor from two of these qualification batches.

Mechanical properties and bonding characterization studies on the selected formulation indicated that all strain and bond requirements dictated by the grain design were met with adequate safety margins. Processing studies confirmed that ANB-3254 propellant exhibited adequate viscosity characteristics, zero-flow time, and propellant-propellant bond. Bonding of this propellant to the selected SD-850-2 liner (used on SL-1 and -2) was excellent with bond strength in excess of the cohesive strength of the propellant.

All objectives of the propellant tailoring program were successfully completed. The target propellant burning rate, a 50% increase over ANB-3105, was achieved with an oxidizer blend possessing a bulk density which did not limit vertical mix batch size. Satisfactory mechanical and bonding property safety margins were maintained along with acceptable propellant processing characteristics. Although additional effort and processing of more propellant batches than anticipated was required to characterize the modified anhydride-free formulation, the effort was accomplished without schedule delay or added program cost. The complete results of the propellant phase are available in NASA Report CR 72262[7].

The chamber was lined with 933 lb of SD-850-2 liner material. The liner was processed in three batches each about 420 lb and hand-applied to the chamber insulation interior surfaces using the same procedures as previously applied for Motors 260-SL-1 and -2. Figure 9 shows the application procedure. The target liner thickness was 0.035 $\pm$ 0.010 in.; the applied weight of liner is equivalent to a uniform thickness of 0.033 in. over the total surface area. Consistency of the application process is also indicated by the applied liner weights in Motors 260-SL-1 and -2 which were 910 and 908 lb, respectively.

The liner was cured in a two-part cycle identical to that used for previous 260-SL motors. First, the environment was maintained at 80 $\pm$ 5^{o}F and 35% relative humidity for 48 hr. For the second part of the cycle, the environment was maintained at 135 $\pm$ 10^{o}F for 48 hr. The lined chamber was then installed in final-test firing-position in the cast, cure, and test facility and the casting core and all other casting tooling were assembled.

Propellant processing was initiated on 13 February and concluded 2 March. During that period a total of 1,656,237 lb of propellant from 320 batches was cast in Motor 260-SL-3. Figure 10 shows cumulative propellant batches cast and weight of propellant mixed as a function of time. All propellant was processed in the batch mixers to enable conduct of the operation at minimum labor level. Although this extended the duration of the propellant processing operations, total cost was minimized as a result of lower peak manpower requirements.

Propellant cure was initiated on completion of casting with the shroud air temperature maintained at 135^{+5}_{-10} °F. The cure cycle was concluded on 5 April. For this cure cycle, mechanical properties tests of samples from every sixth propellant batch cast indicated an average initial modulus of about 450 psi, and liner-to-propellant bond data for samples from every twelfth propellant batch showed bond strength in excess of the propellant cohesive strength. After cure, the grain was cooled for 340 hr with the shroud air temperature maintained at 60 to 65°F. The casting core was removed on 25 April. The net stripping force required was about 53,000 lb which is very close to the values of 50,000 and 46,000 lb required to strip the core on Motors 260-SL-1 and -2, respectively.

D. NOZZLE AND EXIT CONE FABRICATION

The nozzle shell was fabricated by Sun Shipbuilding and Dry Dock Co., Chester, Pennsylvania, using a salvaged section of the S/N 001 (260-SL-1) nozzle shell and a new 18% nickel maraging steel ring-roll forged section. The AISI 4130 steel entrance ring was machined from a single ring-roll forging. Fabrication processes were similar to that of previously fabricated nozzle shells except for the additional processes of welding previously-aged components and local aging of the weld. Prior to implementation on this program, these processes were fully developed and qualified under Contract NAS 3-7965 to establish process controls and assure end-product acceptability.

The ablative plastic components were fabricated by Rohr Corporation, Riverside, Calif., using materials and processes previously demonstrated for Motors 260-SL-1 and -2 components. Materials used were MX 4926 phenolic impregnated carbon cloth manufactured by Fiberite Corporation, Winona, Minn., and FM 5131 phenolic impregnated silica cloth manufactured by U.S. Polymeric, Inc., Santa Ana, Calif. All components were fabricated by tape wrapping. Figure 11 shows tape wrapping of the throat insert.

Nozzle ablative inserts were preformed and cured in a hydroclave at 1000 psig pressure. The preform cycles consisted of a hold period of 2 hr at 150°F and 175 psia to remove volatile materials, followed by a debulk period of 1.5 to 2 hr at 175°F and 1000 psia pressure. The nominal final cure cycle for all components was 2 hr at 150°F and 175 psia pressure to remove volatiles, followed by 1.0 to 1.5 hr at 240°F and 1000 psia pressure for debulk, and 8 hr at 300°F and 1000 psia to complete the final cure.

After final cure, end test rings were removed from both forward and aft ends of each separately-processed billet and test specimens were removed for measurement of mechanical and physical properties. Each insert was also subjected to radiographic inspection.

Nozzle assembly consisted of bonding the submerged nose, entrance, and throat inserts to the insulated entrance ring, bonding of the throat extension insert to the insulated nozzle shell, followed by mating of the nozzle and entrance assemblies by a bolted joint. All inserts were final machined to fit the as-built dimensions of the nozzle shell and entrance ring and dry fit to confirm acceptable bondline thicknesses. Epon 913 epoxy adhesive was applied to mating surfaces, O-ring seals were installed, and inserts were bonded in place. A minimum of 48 hr cure at ambient temperature was required after each separate insert bonding to assure attainment of at least 50 percent adhesive strength level prior to proceeding with subsequent assembly operations. All bondlines were ultrasonically inspected.

The exit cone liner consisted of a parallel-to-centerline wrapped composite carbon and silica overwrapped parallel-to-surface with silica tape. The liner was preformed and cured in an autoclave cycle at 190 psig. Removal of the exit cone liner from the autoclave is shown in Figure 12. Physical and mechanical properties were determined from specimens of end test rings in the same manner as for nozzle ablative inserts. The cured liner was also radiographically inspected.

HT-424 sheet adhesive was applied to the liner for bonding of end flange rings. The glass support structure was built-up by layup of longitudinal sheets of epoxy-impregnated glass cloth and filament winding of epoxy impregnated S-994 glass roving in a 65:35 ratio of roving-to-cloth to achieve cured thickness tapering from 0.62 in. at the forward end to 0.12 in. at the aft end. The glass structure was cured in an autoclave cycle at 300°F and 100 psig pressure.

After cure of the glass structure, ultrasonic inspection indicated a number of unbonded areas amounting to 16.5 percent of the total surface area. Structural analysis of the bonding conditions, using as-built material properties, indicated that positive margins of safety existed; however, additional repair procedures including installation of a bearing ring at the forward end glass overwrap structure were incorporated to provide additional structural margin. This condition and the repair action, and other less significant fabrication discrepancies are discussed in the nozzle phase report[8].

On completion of fabrication, the two assemblies were trial-fit (Figure 13) and installed on separate shipping pallets for transportation by truck to the Aerojet-Dade facility.

E. IGNITION SYSTEM

To reduce the overall ignition system cost, pressure-vessel hardware set, S/N 657117, was used in the ignition motor, S/N 260-IM-08. This pressure-vessel had been subjected to two previous test firings: a static ignition test firing into a 260-SL free-volume simulator and an aft-end ignition motor retention-and-release system demonstration test at the Aerojet-Dade Division(9). To verify the structural integrity of this pressure-vessel prior to use in Motor 260-SL-3, the unit was completely inspected for dimensional conformance to original design, the entire surface was magnetic-particle inspected, and all welds were radiographically inspected. Following NDT inspections, the unit was assembled and successfully proof tested to 2000 psig. The pressure-vessel was then cleaned, painted, and internally insulated with Gen-Gard V-44 rubber. A phenolic-impregnated silica-cloth throat insert was bonded in the aft closure of the pressure-vessel during the insulation operations.

Approximately 1400 lb of ANP-2758 Mod 1 propellant, Batch 4-MM1-17, was mixed and cast in 12 wooden molds. The exposed propellant in the wooden molds was restricted by bonding 0.100-in.-thick vulcanized Gen-Gard V-45 rubber sheets to the propellant surface with SD-850-2 PBAN liner material. Ten restricted propellant slabs were removed from the molds and bonded in the insulated pressure-vessel chamber with Epon 948.2 epoxy adhesive. The forward and aft closures were assembled to the chamber and the AISI-4130 steel exit cone was installed on the aft closure. The completed ignition motor was sealed, packaged, and stored.

Manufacture of pyrotechnic materials and assembly of three ignition motor boosters were accomplished at Aerojet's Von Karman Center. Booster S/N 260-IMB-16 was successfully test fired at the Solid Rocket Operation Test Facility in Sacramento to verify the ballistic performance of the pyrotechnic materials. Booster S/N 260-IMB-14 was shipped to the Aerojet-Dade Division for use in Motor 260-SL-3, and booster S/N 260-IMB-1t was held as a spare unit.

Arc-image furnace tests were conducted to determine the threshold ignition energy requirements for propellant formulation ANB-3254. Propellant samples used consisted of 0.30-in.-dia discs 0.10 in. thick. Ignitability measurements were conducted at nominal flux levels of 70 and 100 cal/cm^2 sec and at pressure levels of 1.5, 10, 25, and 50 psig. Threshold ignition energy, defined as the radiant energy required to ignite the propellant at a 50% probability level was determined by observation of consecutive fire and no-fire samples with the narrowest possible separation of exposure times. Results of these tests indicated that, over the range of flux levels tested, ANB-3254 propellant required from 1/2 to 2/3 of the exposure time required for ignition of ANB-3105 propellant at pressures in the range of 1 to 4.5 atmospheres. These data indicated that satisfactory ignition performance would be obtained in Motor 260-SL-3.

F. MOTOR ASSEMBLY

Motor assembly operations began with final propellant grain trimming. Hand trimming, with in process template checking, was used to remove the over-cast portion of the grain and also to obtain the aft end chamber contour compatible with the submerged nozzle configuration for this motor. Final grain weight after trimming was 1,645,584 lb. Visual inspection of the propellant bore surface showed no evidence of structural failure. However, 158 separate surface anomalies were mapped, approximately 70% of which were located in the forward half of the grain surface. The majority of these surface discontinuities were circumferentially oriented with depths from the surface of 0.05 to 2.0 in. and appeared to be the result of folding of air in the fluid propellant as it flowed against the casting core surface. Bore dimensional inspection indicated that grain deformation after casting core removal was the same as observed in previous motors, with increased aft end slump indicative of a lower effective propellant modulus. The cavity between the aft propellant boot and the chamber aft head insulation was potted with FMC 200 polysulfide molding compound to preclude adverse effects of gas flow behind the released boot.

The conductive rubber burnthrough sensor and probe were bonded to the surface of the forward head insulation with ambient-temperature-curing epoxy adhesive. Wiring for the sensor circuits was routed through an adapter in the chamber forward cap and was covered with Gen-Gard V-61 potting insulation.

On receipt of the nozzle and exit cone assemblies at Aerojet-Dade Division a receiving inspection was performed including ultrasonic inspection of bonds and leak check of the exit cone forward flange. These inspection operations duplicated as closely as possible procedures at the fabricator's facility to assure that no change in bonding conditions had occurred in the interim. Results showed no significant change.

Preparation of the nozzle for installation on the motor included application of IBT-100 trowelable polybutadiene insulation in the cavity between the submerged section and the molded V-44 nozzle shell insulation. The handling fixture was removed from the nozzle assembly and the motor leak test closure was installed on the nozzle aft flange. Prior to trial fit of the nozzle to the chamber, the chamber aft flange was rounded by jacking against the caisson wall; the rounding procedure was the same as previously used to assemble the nozzle shell for the chamber proof test[6].

The motor assembly was leak tested by pressurizing the interior to 50 psig with a mixture of nitrogen and helium gases. A helium leak detector was used to check for leakage at all flanges and fittings. Initial leakage at the "B" nuts of the tubing lines connecting the pressure transducers to the forward cap was corrected by tightening the nuts. No leakage was detected at other locations. Subsequently, check of torque on these "B" nuts showed lower than minimum torque values. The entire pressure transducer assembly was then removed and re-installed using new tubing and fittings. Each pressure transducer installation was then separately pressurized to 75 psig from the interior of the motor and checked for leakage in the same manner as the original motor leak test; no leakage was detected.

After installation of the flight retention system, the exit cone was assembled to the nozzle. V-61 potting insulation was applied to the exit cone aft flange and the weather cover was installed. Installation of the ignition system completed the motor assembly. The complete motor installation is shown in Aerojet Drawing 1005101, Figure 14, and in the photograph of Figure 15.

Installation of sensing instrumentation, wiring, checkout, and end-recorder calibration for 5 pressure, 6 thrust, 14 strain, 30 temperature, and 12 acceleration instrumentation channels was accomplished concurrently with final test equipment assembly operations. A final dry run to verify proper function of the test assembly and operational procedures was conducted 13 June, and the motor was test fired 17 June.

V. RELIABILITY AND QUALITY ASSURANCE

A. SUMMARY

The quality assurance program was conducted in accordance with NASA Quality Publication NPC 200-2. Quality control functions were integrated with the activities of project engineering, manufacturing, and test operations to assure that quality levels would be consistent with those of Motors 260-SL-1 and SL-2. Inspections were performed to determine the acceptability of all components and to disclose potential deficiencies that could result in unsatisfactory performance. Documentation of raw materials, fabrication, and inspection was collected and filed in a Central Quality Data File. These data provide a complete history of fabrication and show, in detail, the identity of every component, thus traceability of all materials in the motor is assured.

B. CONTROL OF CONTRACTOR PROCURED MATERIAL

All purchase documents were reviewed prior to release to ensure that adequate quality provisions were imposed on subcontractors. The suppliers of the nozzle shell and entrance ring, and the nozzle and exit cone assemblies were required to follow NPC 200-2. All others were required to follow selected portions of NPC 200-2 and/or, as minimum, the provisions of NPC 200-3.

Source surveillance was conducted at the suppliers of the nozzle shell and entrance ring, nozzle and exit cone assemblies, chamber insulation, ignition motor insulation and other suppliers. A resident quality representative was located at the nozzle and exit cone fabricator's facility for the full period and a resident representative was located at the nozzle shell fabricator's facility during all welding and heat-treating operations. All other source surveillance was conducted on an itinerant basis. Quality representatives accepted the nozzle shell and entrance ring, the nozzle and exit cone assemblies, the chamber insulation, and the insulated ignition motor at the supplier's facilities.

Supplier quality program plans, required of the nozzle shell and nozzle and exit cone fabricators, were submitted to NASA for information.

C. CONTROL OF AEROJET FABRICATED ARTICLES

All process activities were defined by project directives that referenced the drawings and specifications and directed the sequence and scope of the activities. A project directive also specified the statistical quality control plan for sampling and testing chemicals, submixes, and finished propellant. Detailed integrated processing and inspection planning, prepared jointly by Manufacturing and Quality Control, specified the actual equipment, conditions, and inspection techniques to be used for each operation.

Control charts were maintained during the propellant processing operations for controlling key parameters (e.g., liquid strand burning rate and liquid density) so that control adjustments could be made rapidly.

Selected project engineers conducted quality control surveillance and inspection during the propellant mixing and casting operations and the hydrostatic testing of the chamber.

D. NONCONFORMING MATERIAL

Materials which did not conform to Aerojet drawings and specifications were documented on inspection reports (IR's, QRR's, SDAR's) and were subjected to engineering review (ERB). Disposition of significant departures was discussed with NASA prior to the ERB decision. MRB was conducted during the propellant mixing and casting operations with NASA program engineers representing the Government.

All inspection reports of nonconforming material generated while the program was in progress were transmitted to NASA.

E. ENGINEERING QUALITY EVALUATION

Engineering evaluation meetings were conducted with suppliers to assess the quality of the finished nozzle and exit cone components and assemblies. An additional meeting was conducted by NASA and Aerojet to review the final assembly of Motor 260-SL-3 prior to the test firing. The purpose of the meetings was to establish the acceptability of the components and assemblies before committing them to further processing or testing.

F. QUALITY DATA

Documentation including nonconformance reports, acceptance records, and process variability data was collected and filed in the Central Quality Data File to be used for analysis and reference purposes. This documentation is described in a Table of Contents, Appendix A, which was previously submitted to NASA for review.

G. CORRECTIVE ACTION

In accordance with Paragraph 14.3 of the Quality Assurance Plan, recommended changes to future design or fabrication activities are presented below.

1. Nozzle Shell Weld Defects

Although the weld defects occurring in the joining of the two conical shell sections were minor for this particular strength requirement, particular effort should be made to minimize contamination during weld preparation, welding, and weld repairing.

2. Nozzle and Exit Cone Fabrication

a. Tape Wrapping Parameters

There is no accurate and brief method for determining the degree of resin advancement of tape materials which occurs during the wrapping process. Instead, estimated shop limits are established for the operator's control of process variables. A slight error by the operator in adjusting, or his failure to adjust, for process anomalies could result in detrimental effects on the density of the wrapped part. Therefore, time, temperature, and pressure limits should be specified for automatic control of wrapping variables which would permit optimum compaction and tacking of materials and would assure that the temperature history of the tape increments is not so high as to induce premature resin advancement.

While it is desirable that finished billets have uninterrupted and smooth ply orientation, changes in laminate orientation such as wrinkles and folds will occur. The effect of these defects in the end product should be determined and acceptance limits established to preclude the necessity of reviewing every occurrence.

The wrapping of the first few plies of the silica tape overwrap consistently produced wrinkled and crushed tape due to: (1) inadequate wrapping-head guidance which caused partial overlapping of the tape and (2) the necessity to overlap when starting a new pass of tape over the surface.

The alternatives for solution of this problem are: (1) a relaxation of the requirement for very high (85%) as wrapped density for the overwrap process and (2) investigation toward possible use of unidirectional materials which can be overwrapped under moderate tension, thereby giving a smooth uniform orientation in the cured billet.

b. Bagging for Autoclave Curing

To eliminate the recurrence of bag failures during autoclave processing of ablative parts,it is necessary to assure bag integrity under pressure by adequate bag protection.

c. Adhesive Bonding of Ablative Components

A need for a detailed review from design to fabrication is indicated by the deviations encountered in the adhesive bonds of the steel to ablatives. These deviations consisted of voids caused by:

(1) Insufficient adhesive volume.

(2) Improper tooling for aligning steel and plastic during dry fit and assembly.

(3) Inadequate process control and planning in that the O-rings were not inserted during the dry fit and did not compress by virtue of the weight of the steel assembly during final fit.

(4) A design incompatibility with accepted practices for adhesive bonding of ablative parts, in that the O-ring seal on one end of an ablative part and a requirement for a silicone gap sealant on the outer end prohibit the use of surplus adhesive to assure a good bond.

A number of rejection reports were written because lap shear panels representing adhesive bonds of various components showed low shear values. These panels were prepared by shop personnel using improper fixtures and no manufacturing planning. It was therefore concluded that because of the extensive data showing reliable shear values obtained with this resin system, inadequate control of the panel's preparation rather than a deficient resin system was the cause for the low values. Sufficient planning and inspection detail should therefore be provided for this operation to assure reproducible and reliable panel preparation.

d. Exit Cone Structural Overwrap

The need for an adhesive system with a very long working life (over 10 days) at ambient temperatures is demonstrated by the occurrence of voids between the exit cone liner and the structural overwrap.

3. Propellant Processing, Casting, and Curing

Oxidizer hangup in the inlet chute continually caused rejections to be documented. If future propellant formulations for this program are to contain significant percentages of oxidizer fines, a facility modification is required. Six rejections were recorded for exceeding the prescribed 10-batch running average liquid-strand burning rate action limit. The burning rate additive concentration was adjusted in initial corrective measures but the burning rate continued to fluctuate randomly and drift out of range. Control was achieved by varying oxidizer blend ratios on a batch-to-batch basis. The cause of the excessive burning rate fluctuations is unknown, therefore, decisive corrective action cannot be recommended without further study.

4. Igniter Motor Processing

A recurring problem is indicated in that the heat of combustion of boron-barium chromate powder used for all igniter boosters was low. This appears to be typical of most powder lots, and since all igniter boosters performed with no deviations from design, it is apparent that the specification should be reviewed for possible revision.

VI. SUMMARY OF TEST FIRING RESULTS

The full-duration static firing of Motor 260-SL-3 achieved the significant test objectives. A detailed analysis of performance of all motor components, including discussion of ballistic performance anomalies and data on operation of all test systems, is contained in the Static Test Firing Report.[10]

The ignition transient of Motor 260-SL-3 essentially duplicated that of Motors 260-SL-1 and -2. The ignition motor performance met design requirements; flame propagation, ignition interval, and mass flow rate were well within design limits. The release control unit operated normally and the explosive bolts retaining the igniter support system were actuated at 0.284 sec. The ignition motor and support fixture traveled vertically after leaving the channel track. The tether cables fractured without imparting eastward impulse and the unit impacted about 150 yd south of the motor. Tower retraction was manually actuated at 12 sec.

As shown by Figure 16, motor chamber pressure stabilized initially at a level just slightly below that predicted. Chamber pressure and thrust increased sharply at 1.23 sec, then were smoothly progressive until 11.26 sec when another abrupt increase occurred. While these anomalies are not major performance deviations, they are indicative of abnormal propellant burning. This behavior is characteristic of a sudden increase in propellant burning surface area such as may result from exposure of cracks, fissures, or voids within a propellant grain, or from exposure of propellant surface at the propellant-to-liner bond at grain boundaries.

Maximum chamber pressure and thrust values of 643 psia and 5.88×10^6 lbf respectively, occurred at 25 sec. Performance was then smooth and continuously regressive until 55 sec when another anomaly occurred. Observed performance during the first 55 sec of motor operation can best be explained by assuming that flaws within the grain were exposed and separate increments of added burning surface were ignited at 1.23 and 11.26 sec, respectively.

At 55.17 sec, a third sharp chamber pressure and thrust rise occurred, followed by another at 55.90 sec, both of which were of the same nature as the two prior anomalies. Chamber pressure and thrust were then quite sharply regressive until 65.48 sec. At that time both pressure and thrust began to rise, gradually at first, and then accelerating rapidly. At 66.20 sec, with chamber pressure increasing rapidly, axial thrust showed a sharp negative transient, and then increased rapidly while registering severe thrust stand vibration. After attaining peak values at 66.4 sec, pressure and thrust decreased rapidly, and by 67 sec had decreased to the levels existing prior to the upset. The observed performance during the time interval from 66.18 to 67 sec is indicative of nozzle obturation, that is, solid material passing through the nozzle. Based on the recorded performance data, together with visual and motion picture observation and the existence of chunks of unburned propellant around the test site after motor firing, it appears probable that portions of the propellant grain were broken up and expelled from the motor at this time.

Analysis of ballistic data indicates that the nozzle expansion ratio was reduced from 3.8 to about 2.5 during the period of upset after 66.18 sec. This is consistent with data from other motor instrumentation and motion picture coverage, which indicates that the aft portion of the exit cone separated and was ejected at this time.

During the subsequent period of propellant web burnout and motor tailoff, six additional anomalies occurred, each of which was similar to the one at 66.18 sec, though of much lesser magnitude. The recorded pressure and thrust and motion picture coverage indicate that each of these upsets included ejection of portions of the propellant grain. Other motor instrumentation and motion picture coverage indicate that the remainder of the exit cone was ejected at 77.62 sec. There was no indication of abnormality in the ballistic data at this time.

The integral of measured chamber pressure vs time was almost equal to predicted while the thrust-time integral was slightly greater than predicted. Thus, the mass of ejected propellant must have been an insignificant portion of the total grain weight. Data analysis indicates that actual propellant burning rate referenced to a chamber pressure of 600 psia was 0.729 in./sec which is nearly identical to the expected value of 0.726 in./sec. Data analysis also indicates that the actual nozzle efficiency factor, that is, the ratio of the delivered thrust coefficient to the theoretical thrust coefficient for this nozzle was 0.988 compared with the expected value of 0.980. As a result, the standard specific impulse obtained was 248 lbf-sec/lbm, which exceeded the predicted value of 246 lbf-sec/lbm.

The inert slivers did not produce the marked slope change in the pressure-vs-time curve which was expected to occur at 86 sec. This effect was evidently masked by the previous ballistic performance abnormalities.

Recorded data from electrical circuits of the burnthrough sensor showed the expected sharp decrease of circuit resistance as each separate layer was exposed to gas flow.

Erosion of the nozzle plastic inserts was close to, or slightly less than, predicted values at all locations except the silica/phenolic portion of the insert on the exterior of the submerged section. The difference appears to be the result of inaccuracy in gas flow conditions at the base of the cavity that were used in prediction. Eroded surfaces were smooth and uniform, except for local areas of char loss which may be attributable to impact of chunks of propellant that were expelled from the motor. Surface of the throat insert can be seen in Figure 17. Erosion of the nozzle insulation was less than predicted and displayed a grain-oriented pattern of differential erosion similar to that observed in the nozzle of Motor 44-SS-4(11). Since failure of the exit cone caused exhaust gas impingement which rendered the motor quench system inoperable, the nozzle components were subjected to excessive post-test heat soak and valid char depth measurements could not be obtained.

Discoloration of chamber exterior paint due to excessive heating was observed at ten separate localized areas. Significant surface contour deviations were measured in two of these areas. Post-test inspection of chamber interior insulation revealed excessive material loss at locations coincident with observed exterior paint discoloration. Since insulation material loss in other areas was normal, it appears that the propellant burning anomalies resulted in the areas of longer exposure of the insulation to exhaust gases and consequent greater insulation erosion. There is no indication of inadequacy of insulation performance.

VII. CONCLUSIONS AND RECOMMENDATIONS

The basic program objective of design, fabrication, and test of a short-length 260-in.-dia motor was achieved. Overall schedule requirements were met culminating with static test firing of the motor in June 1967, in compliance with contractual requirements. Tooling, materials, and motor components residual from the previous 260-in.-dia motor Feasibility Demonstration Program were used wherever possible. The program was planned so that the level of effort was minimal and as nearly constant as possible. In this manner, resources of manpower and facilities required for design, fabrication, and processing of 260-in.-dia motors were maintained for the contractually-required period at minimum cost.

Test firing of Motor 260-SL-3 demonstrated the adequacy of design concepts and materials and fabrication techniques selected for ablative nozzles of the basic configuration proposed for use with thrust vector control systems, in a nozzle with the same throat size as required for full-length 260-in.-dia motors. Further confirmation of the adequacy of design, and material and fabrication process selections for the chamber, insulation, and igniter system was also provided. The observed propellant burning anomalies appear to have resulted from propellant bonding discrepancies, indicating the combination of propellant flow characteristics during casting and the casting procedures used are not adequate for producing completely sound propellant grains.

The 260-SL-3 Motor Program, together with the previous 260-in.-dia motor Feasibility Demonstration Program which included Motors 260-SL-1 and -2, provides a sound base for continued effort directed toward 260-in.-dia booster-stage development. It is recommended that succeeding program effort include:

A. Thrust vector control system evaluation and demonstration.

B. Demonstration of processing methods for and performance of, a grain design meeting for proposed vehicle requirements.

C. Development of improved propellant processing techniques and/or propellant formulation tailoring to improve flow characteristics during casting to assure attainment of reliable propellant bonding.

D. Flight-type ignition system demonstration.

VIII. LIST OF REFERENCES

(1) Program Plan, Motor 260-SL-3 Aerojet-General Corporation Report PP-1, dated 15 July 1966

(2) Report NASA CR 72127 260-in.-dia Motor Feasibility Demonstration Program, Final Program Summary Report, dated 8 April 1966

(3) Report NASA CR 54865 260-in.-dia Motor Feasibility Demonstration Program Static Test Firing of Motor 260-SL-1, dated 25 October 1965

(4) Report NASA CR 54982 260-in.-dia Motor Feasibility Demonstration Program Static Test Firing of Motor 260-SL-2, dated 25 March 1966

(5) Report NASA CR 72228 260-SL-3 Motor Program, Volume I: 260-SL-3 Motor Internal Insulation System, dated 28 April 1967

(6) Report NASA-7998 HTR-1 Final Report, Hydrostatic Test of 260-SL-3 Motor Chamber and Nozzle Shell, dated 11 November 1966

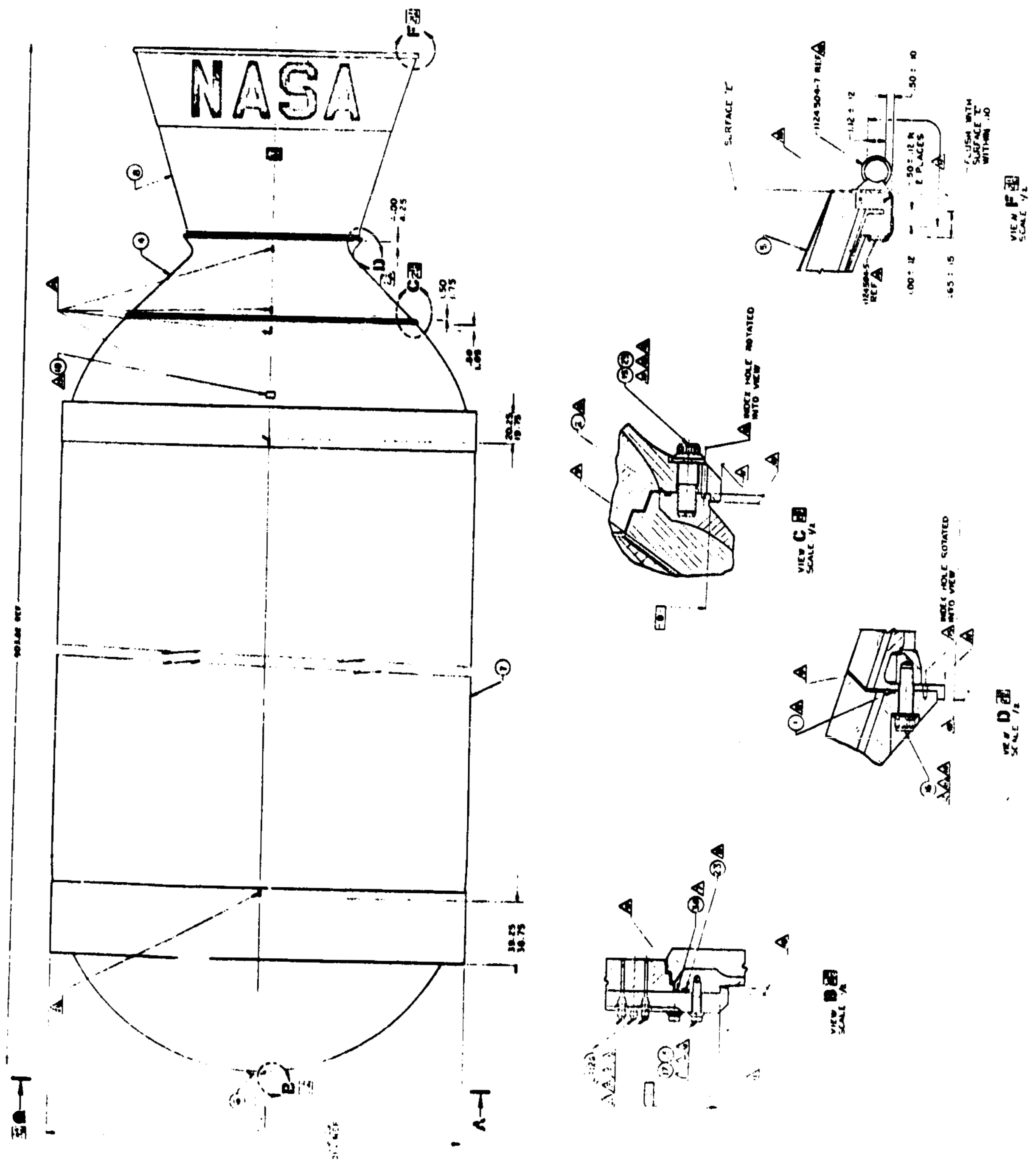
(7) Report NASA CR 72262 Final Phase Report 260-SL-3 Motor Program, Volume II: 260-SL-3 Motor Propellant Development, dated 14 July 1967

(8) Report NASA CR72283 Final Phase Report, 260-SL-3 Motor Program, Volume III: 260-SL-3 Motor Nozzle and Exit Cone Design, Fabrication, and Assembly.

(9) Report NASA CR54454 260-in.-dia Motor Feasibility Demonstration Program Final Phase Report, Volume I: 260-SL Motor Aft-End Ignition System Development, dated 20 August 1964

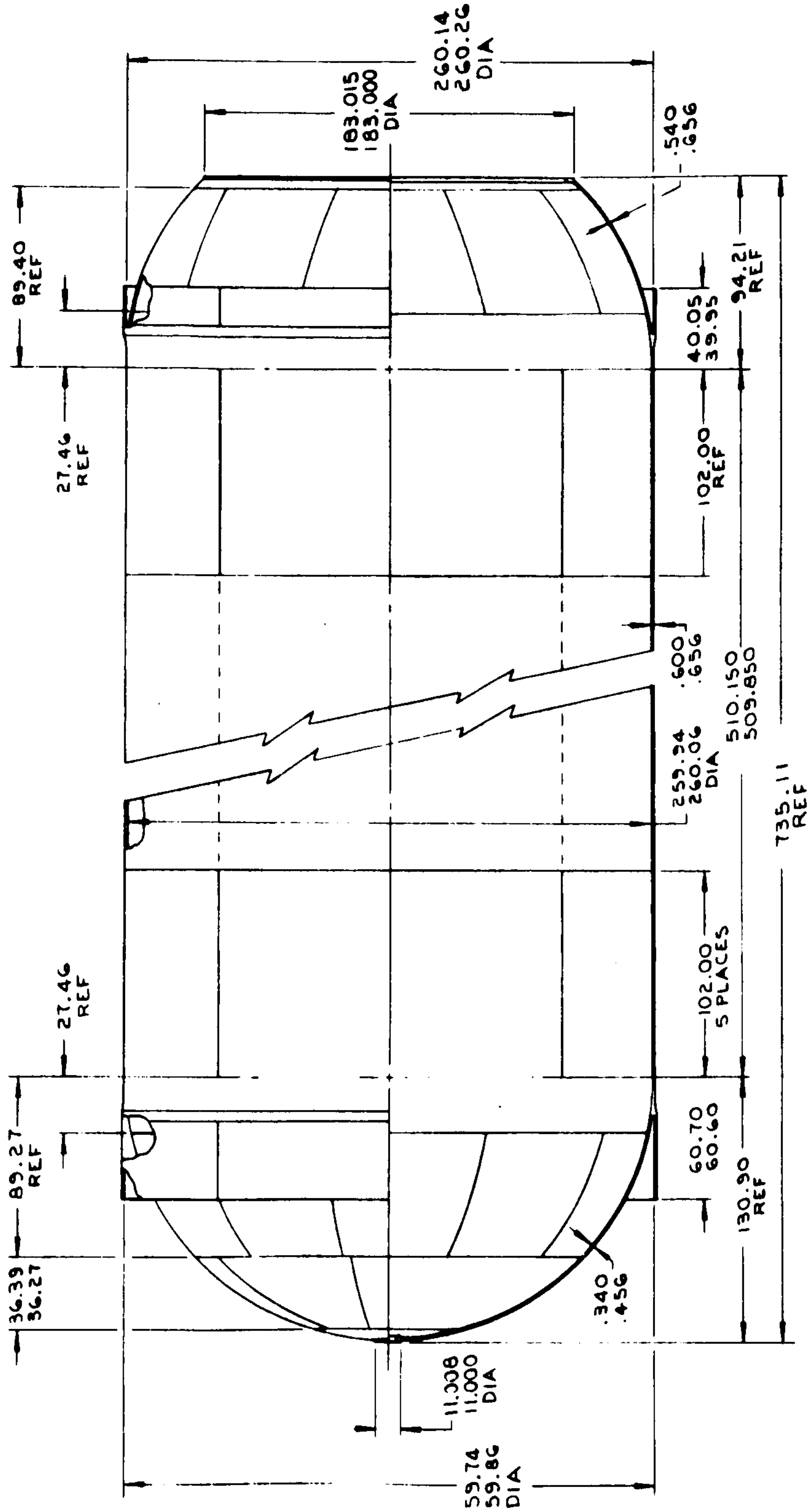
(10) Report NASA CR 72284 Final Phase Report, 260-SL-3 Motor Program, Volume IV: Static Test Firing of Motor 260-SL-3

(11) Report NASA CR72287 260-in.-dia Motor Feasibility Demonstration Program, Static Test Firing of Motor 44-SS-4, dated 19 May 1967



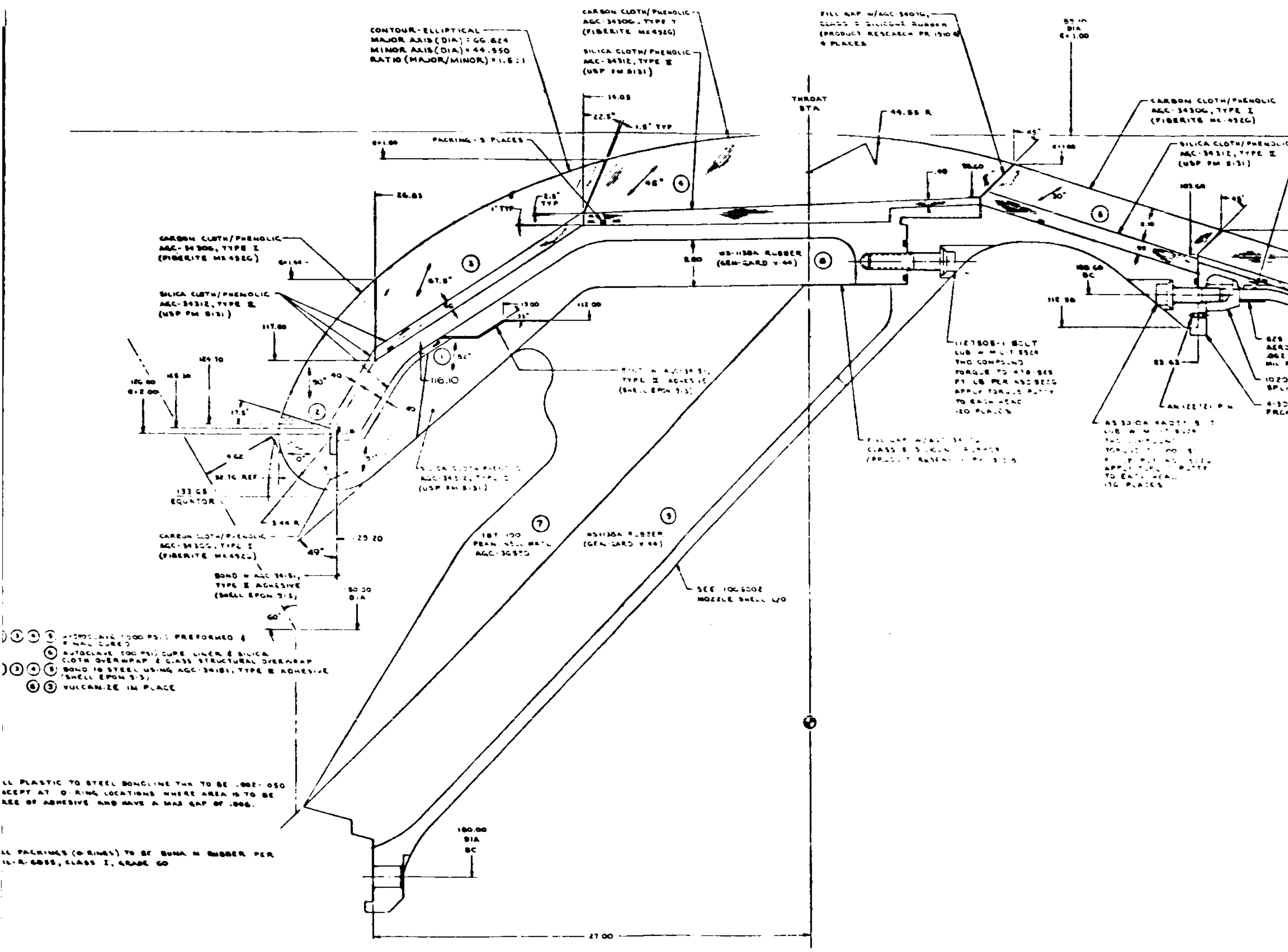
260-SL-3 Motor Assembly

Figure 1



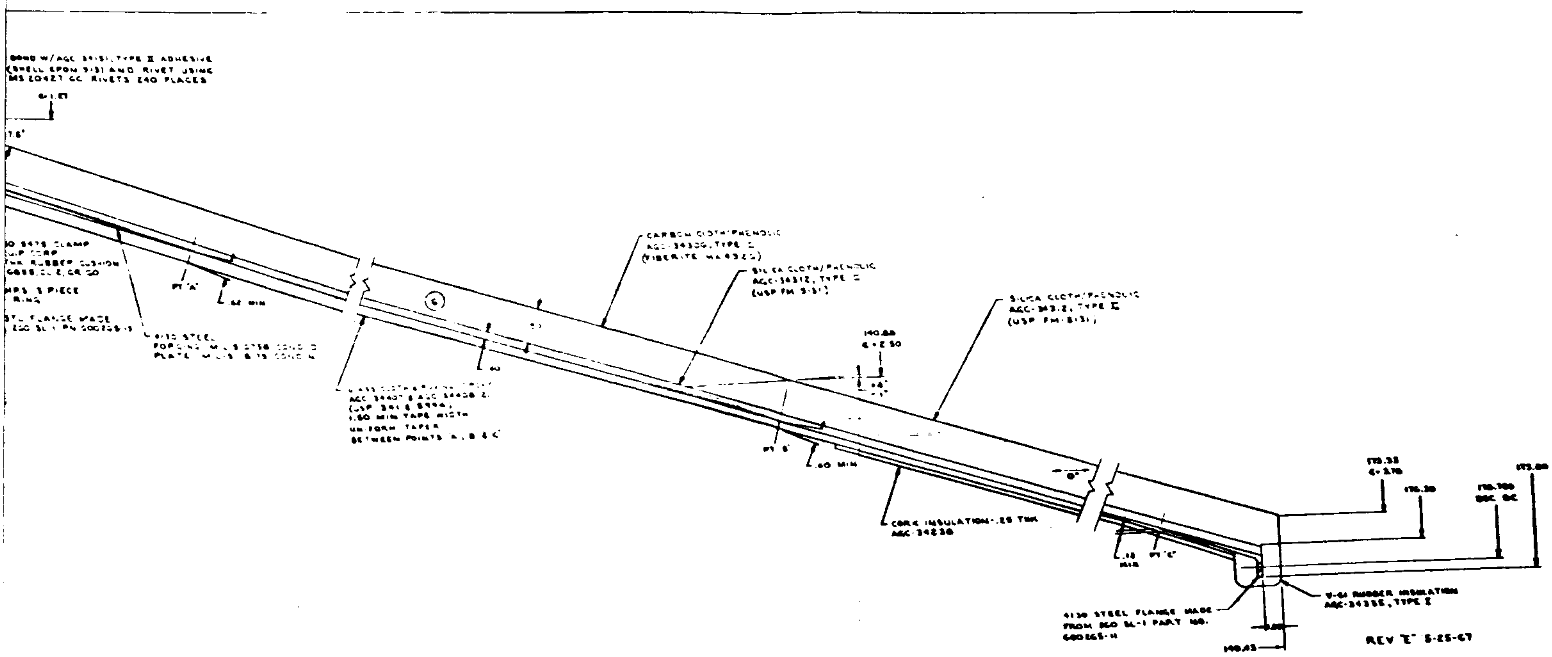
260-SL-3 Chamber Configuration

Figure 2



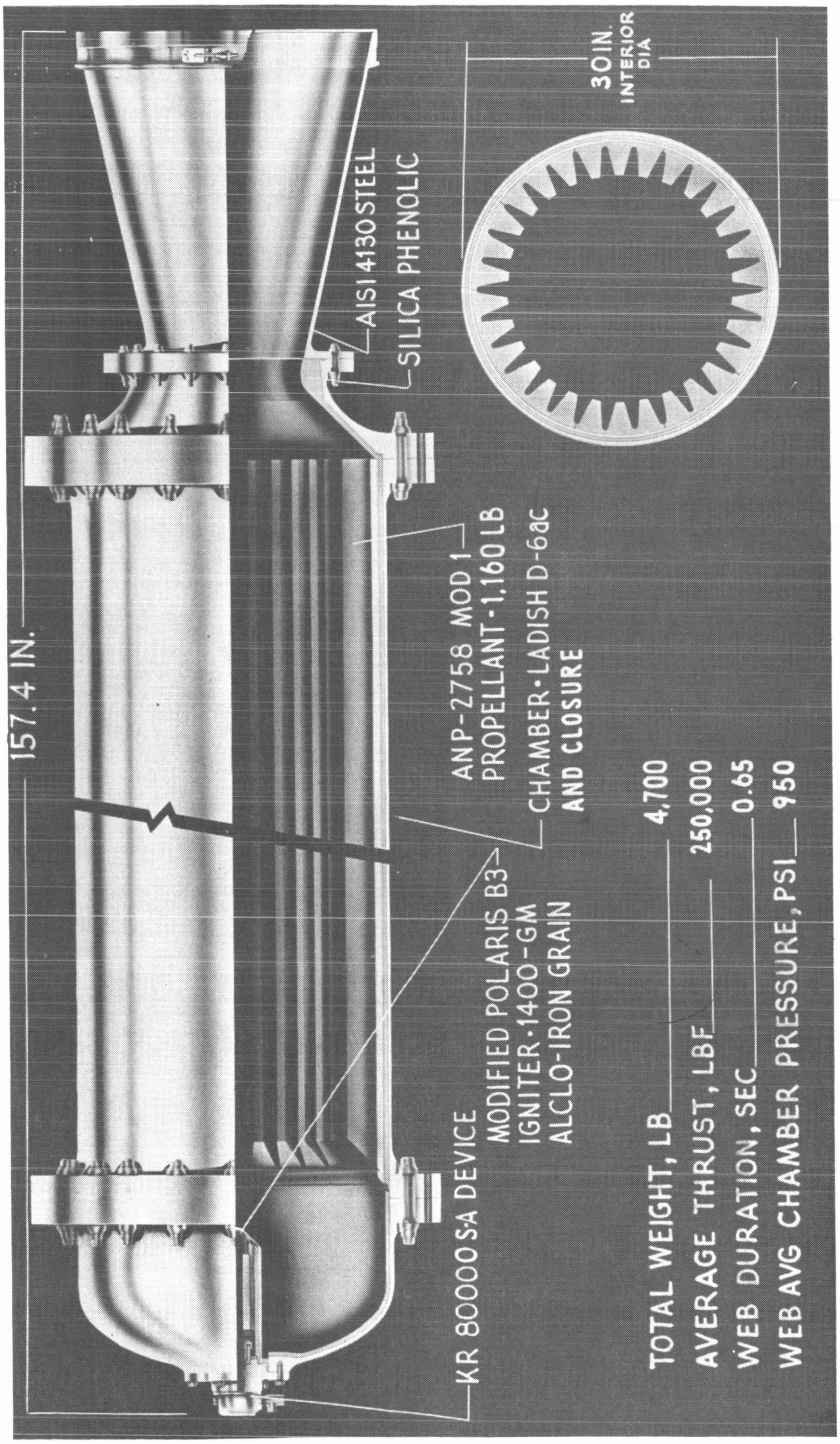
CONTOUR-ELLIPTICAL
MAJOR AXIS (DIA) = 66.824
MINOR AXIS (DIA) = 44.550
RATIO (MAJOR/MINOR) = 1.5:1
CARBON CLOTH/PHENOLIC
AGC-34306, TYPE I
(FIBERITE MX4926)
SILICA CLOTH/PHENOLIC
AGC-34312, TYPE II
(USP FM 8131)
THROAT
STA
44.86 R
PACKING - 3 PLACES
22.5°
1.5° TYP
2.5° TYP
1° TYP
46°
67.5°
30°
49°
60°
2.80
36.83
19.00
112.00
116.10
125.00
117.00
133.65
EQUATOR
WS-1138A RUBBER
(GEN-GARD V-44)
18T-100
PEAR NSL MATL
AGC-36570
SEE 10065002
NOZZLE SHELL L/O
27.00
180.00
DIA
BC
108.60
BC
112.86
83.63
BOND W AGC-34181,
TYPE II ADHESIVE
(SHELL EPON 913)
ALL PLASTIC TO STEEL BONDLINE THK TO BE .002-.050 EXCEPT AT O-RING LOCATIONS WHERE AREA IS TO BE FREE OF ADHESIVE AND HAVE A MAX GAP OF .006.
ALL PACKINGS (O-RINGS) TO BE BUNA N RUBBER PER MIL-R-6855, CLASS I, GRADE 60

Figure 31



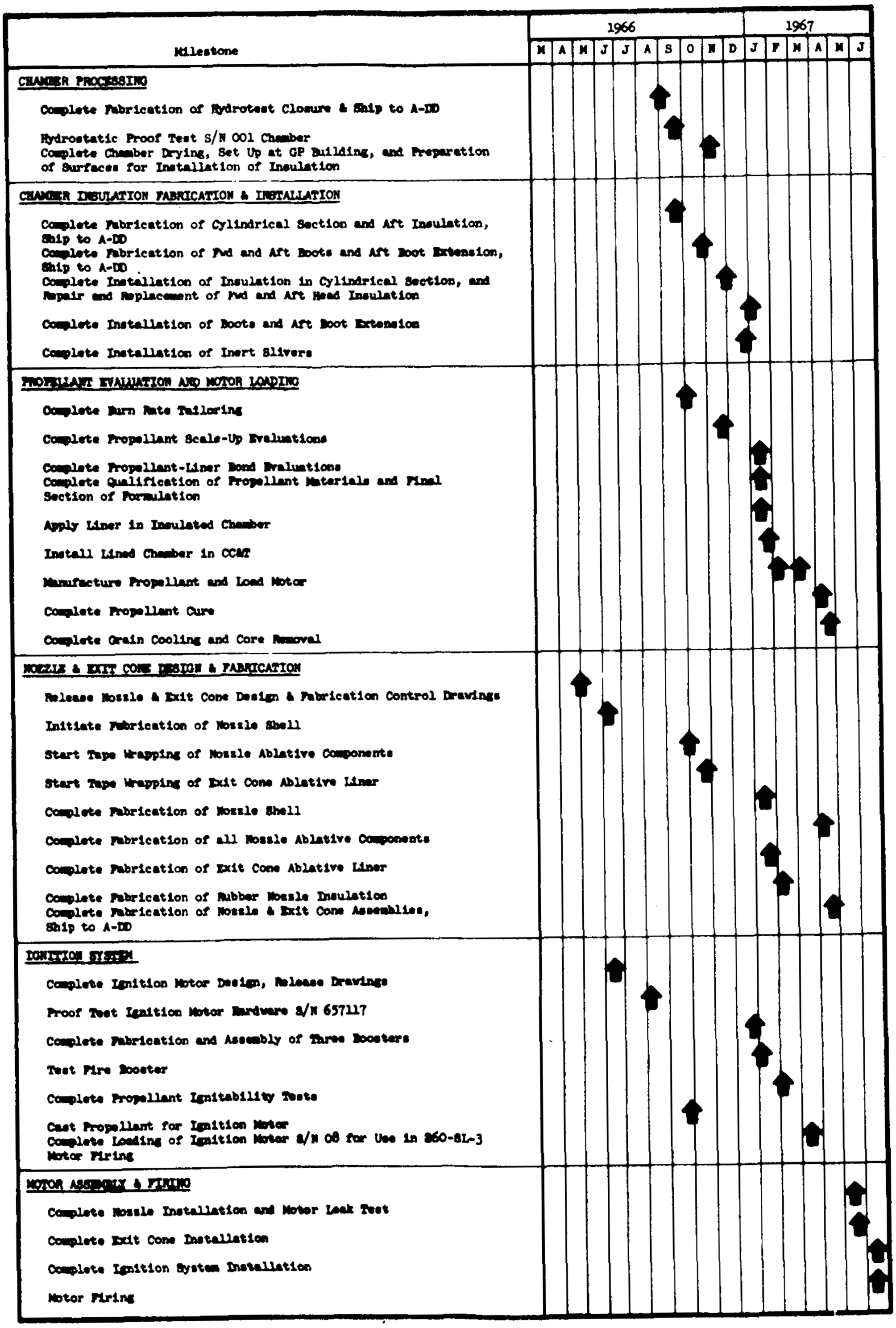
260-SL-3 Nozzle and Exit Cone

Figure 3 - 2



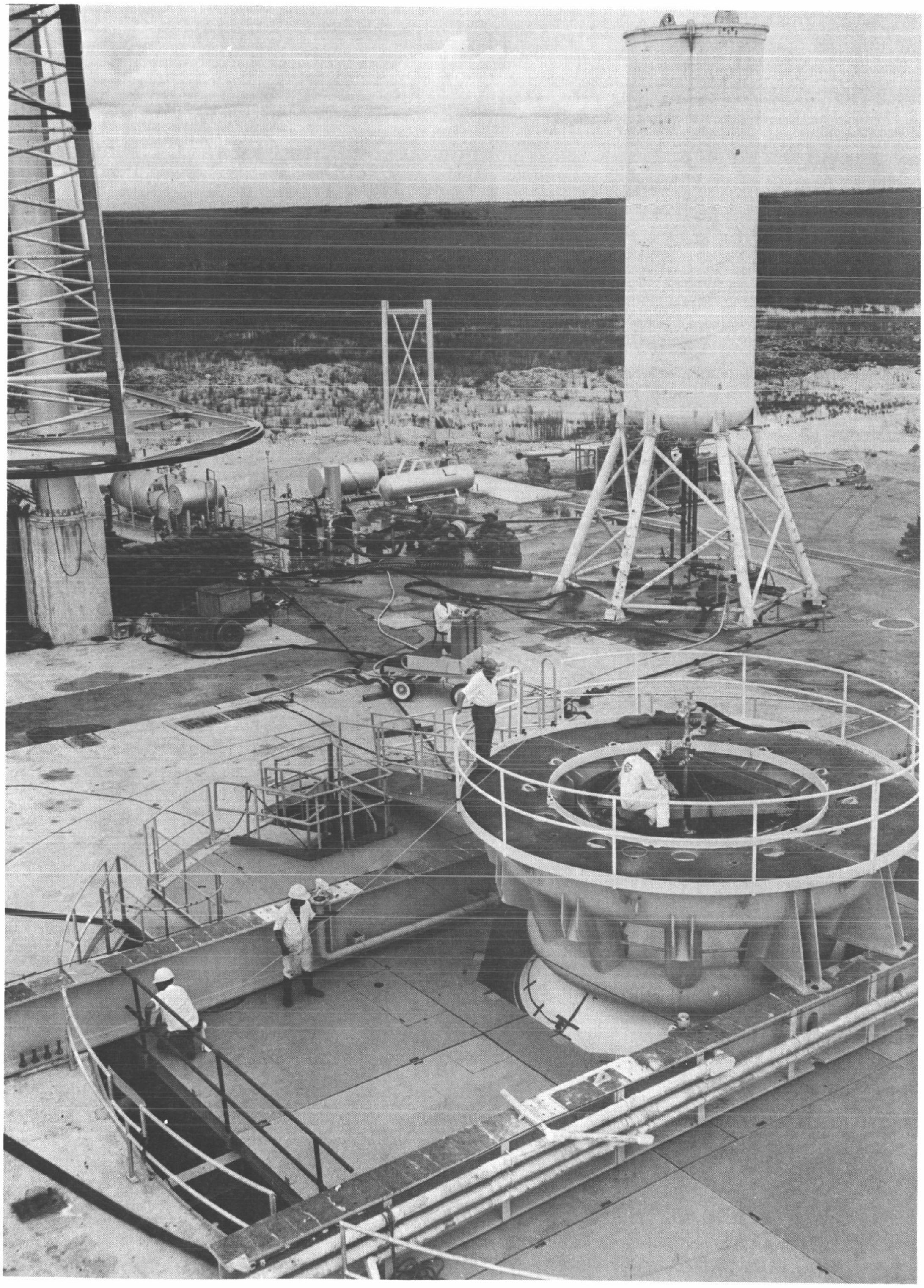
Aft End Ignition Motor for 260-SL Motors

Figure 4



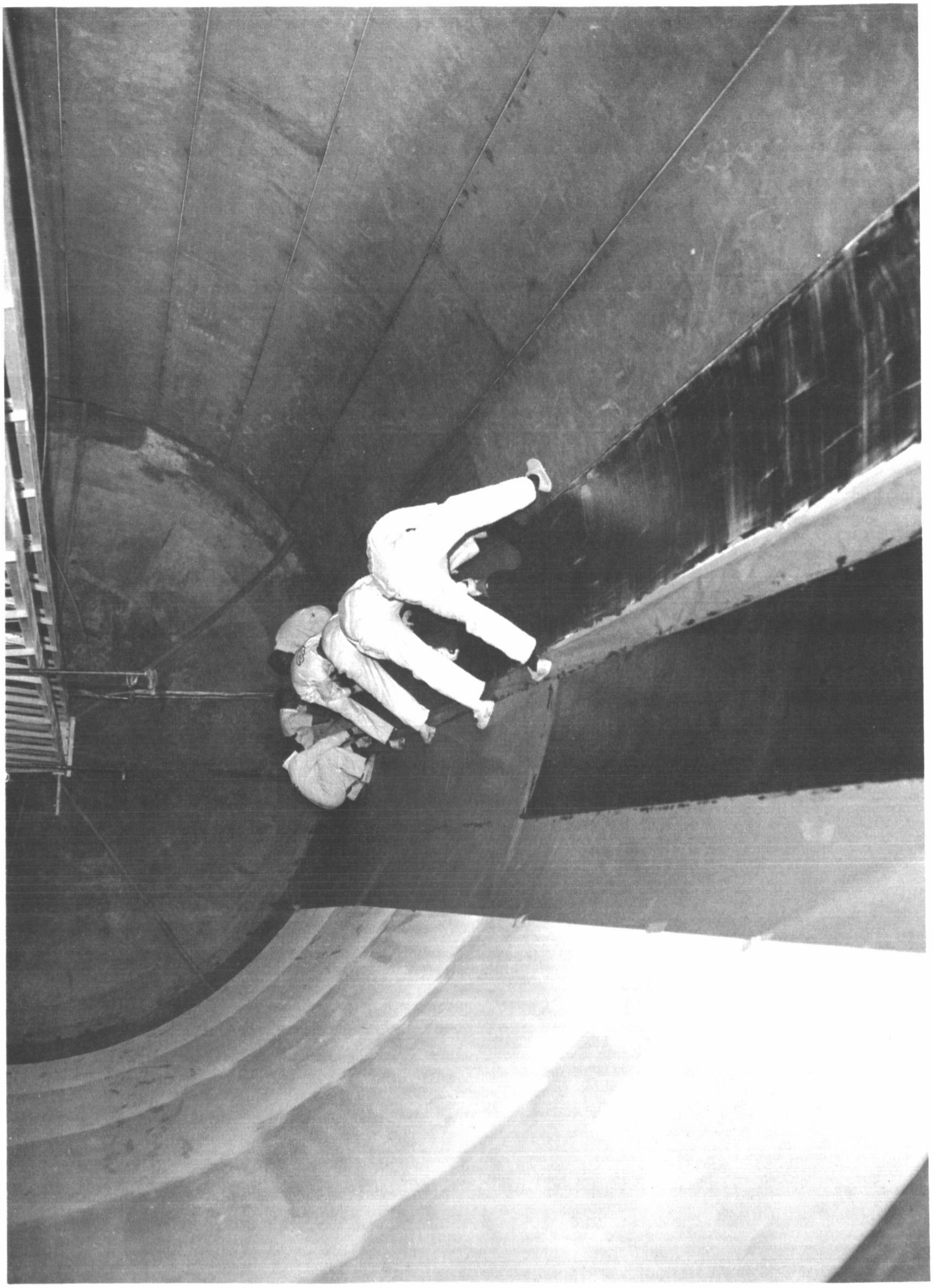
260-SL-3 Motor Program Milestone Chart

Figure 5



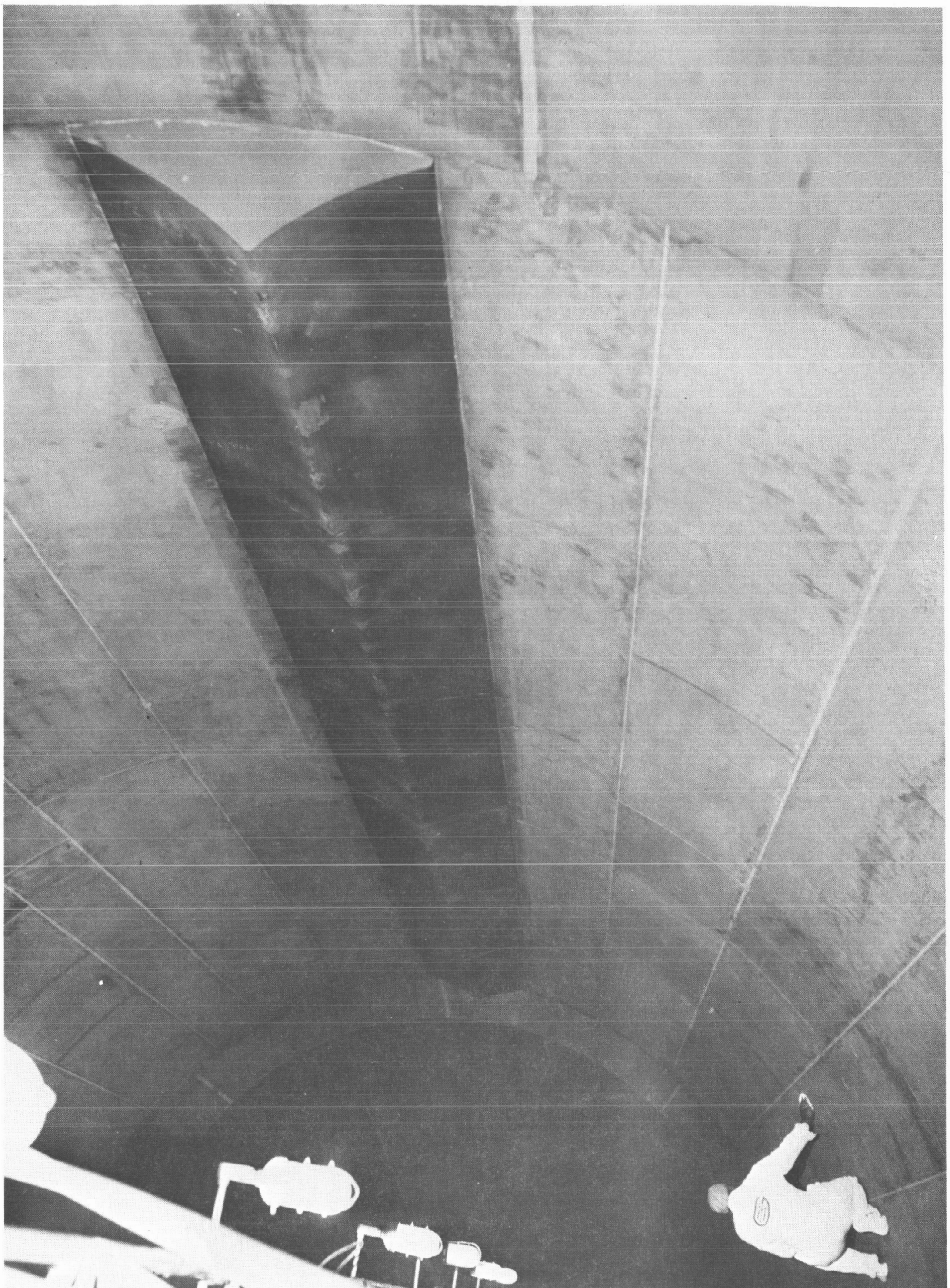
Chamber Hydrostatic Test Setup

Figure 6



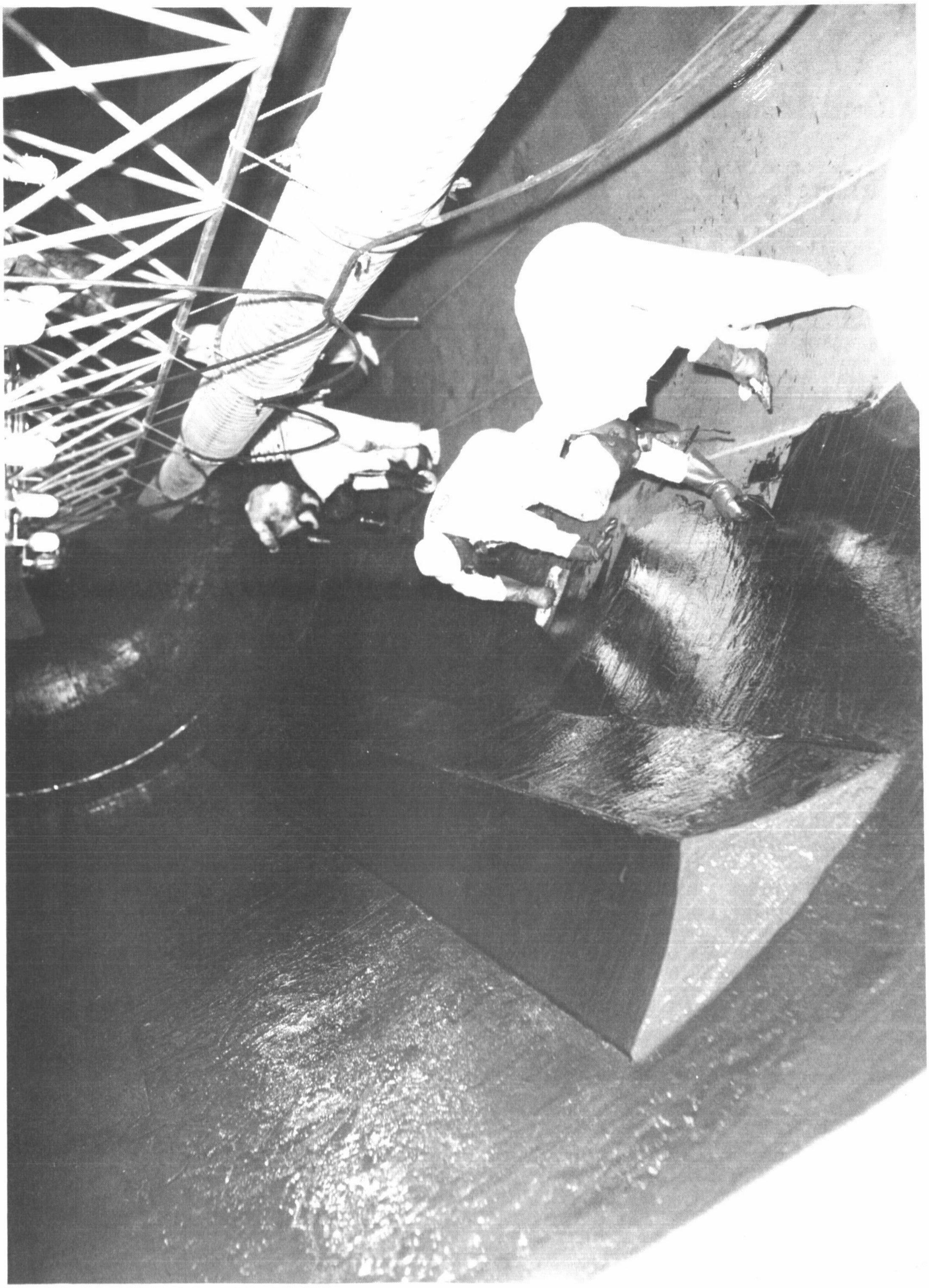
Installation of Chamber Cylindrical Section Insulation

Figure 7



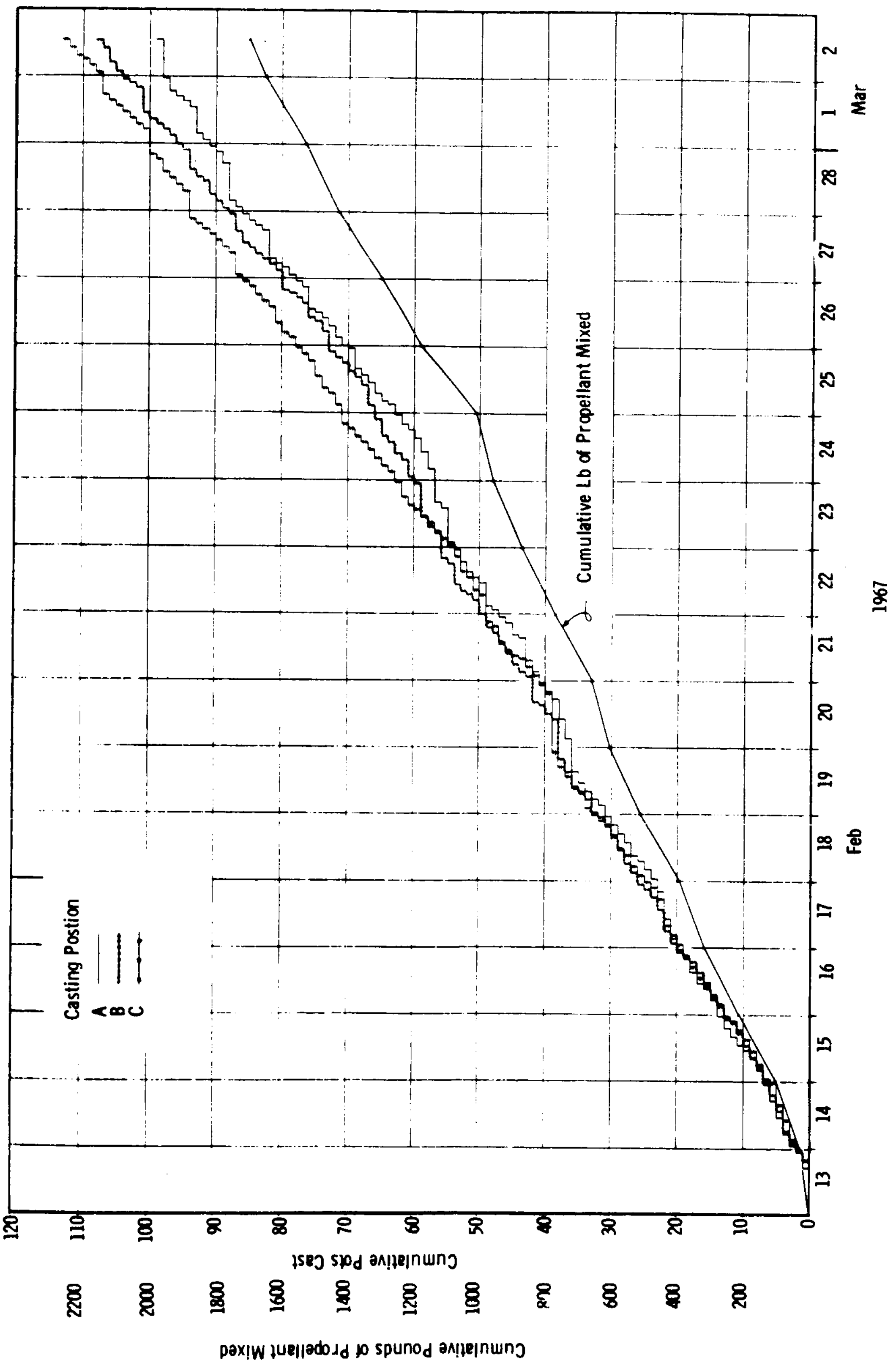
Inert Sliver Bonded in 260-SL-3 Chamber

Figure 8



Liner Application

Figure 9

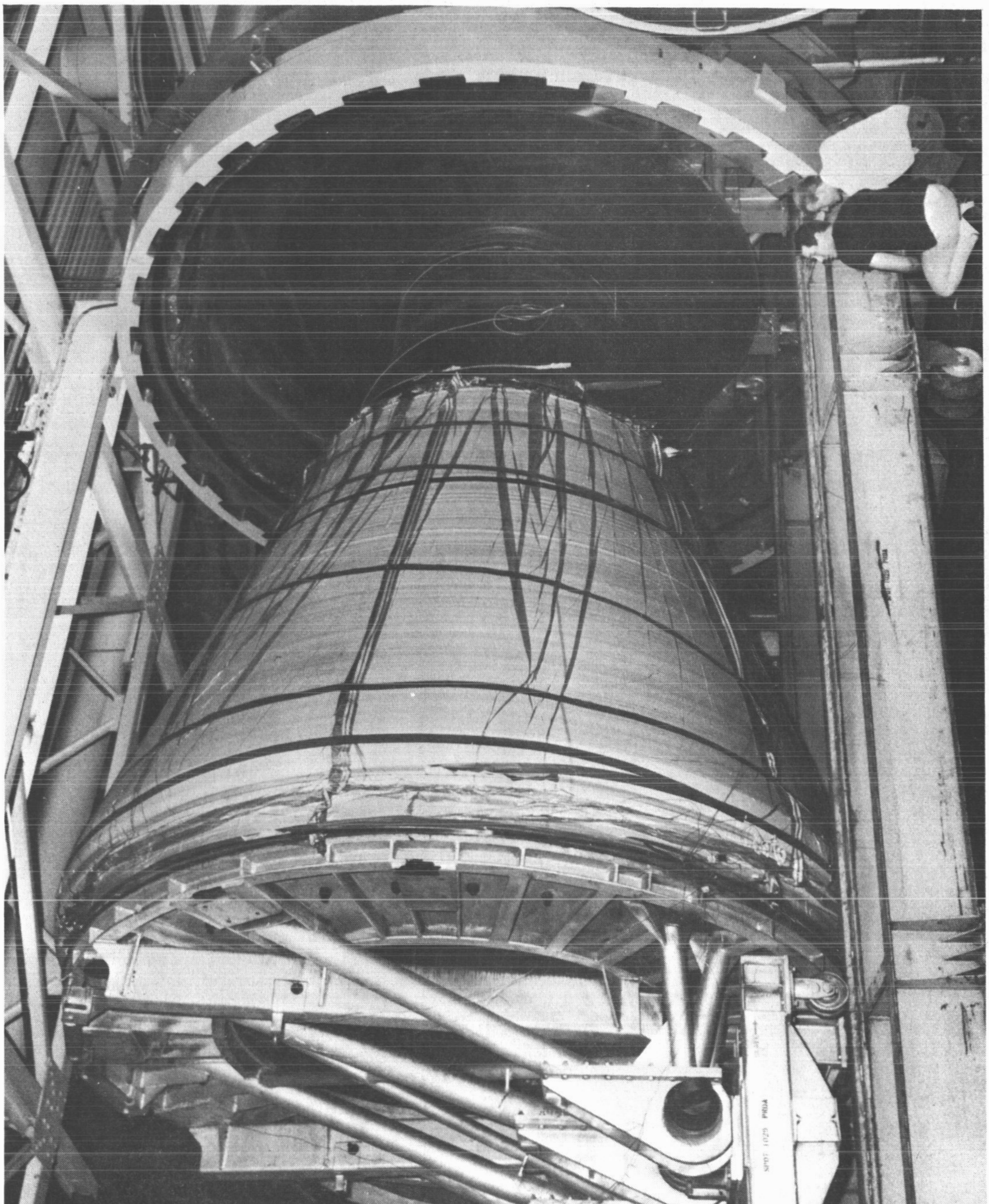


Propellant Cast Summary Chart

Figure 10

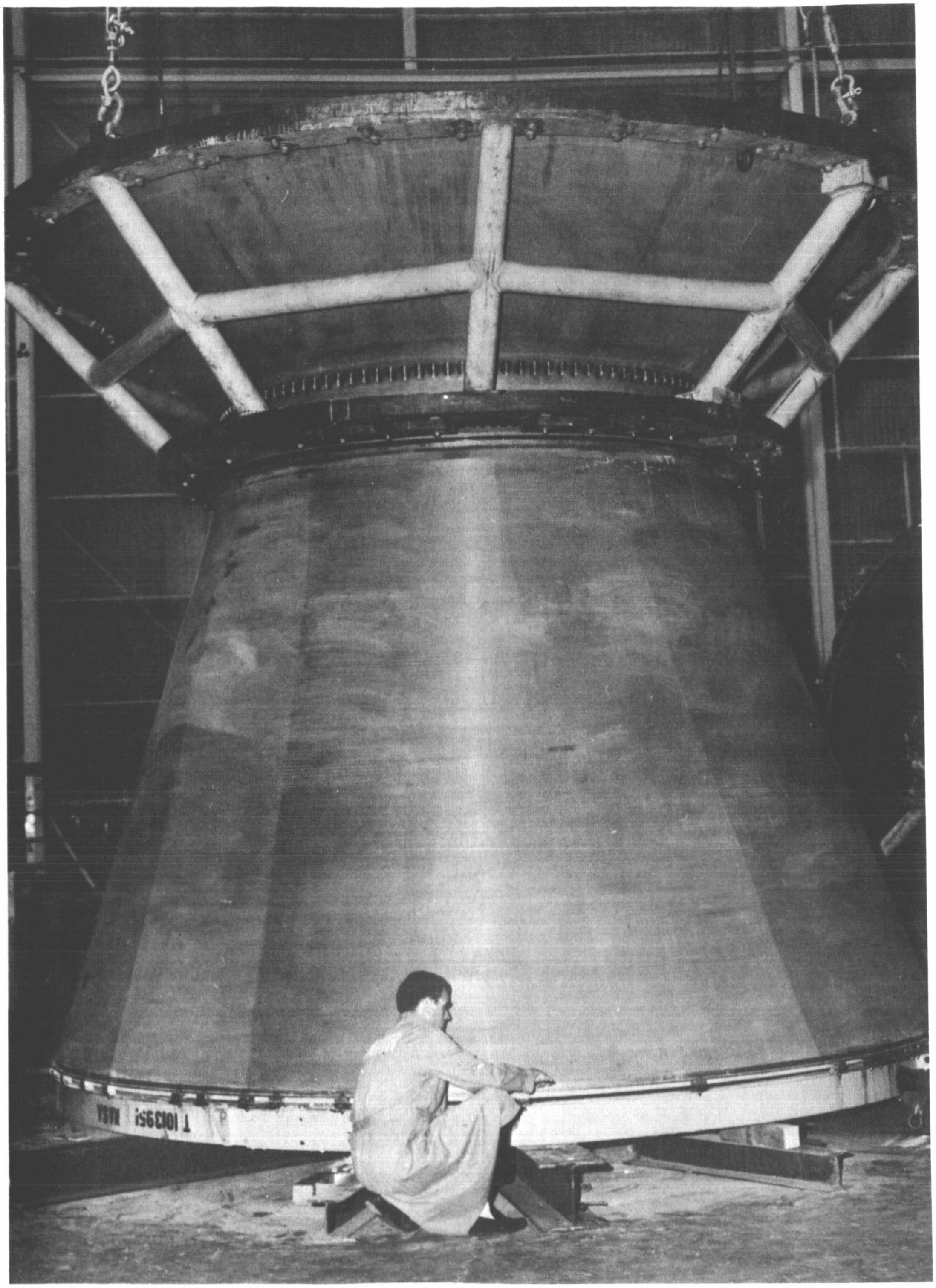
Tape Wrapping of the Nozzle Throat Insert

Figure 11



Removal of Exit Cone Liner from Autoclave after Cure

Figure 12



Fitting of Nozzle and Exit Cone Assemblies

Figure 13

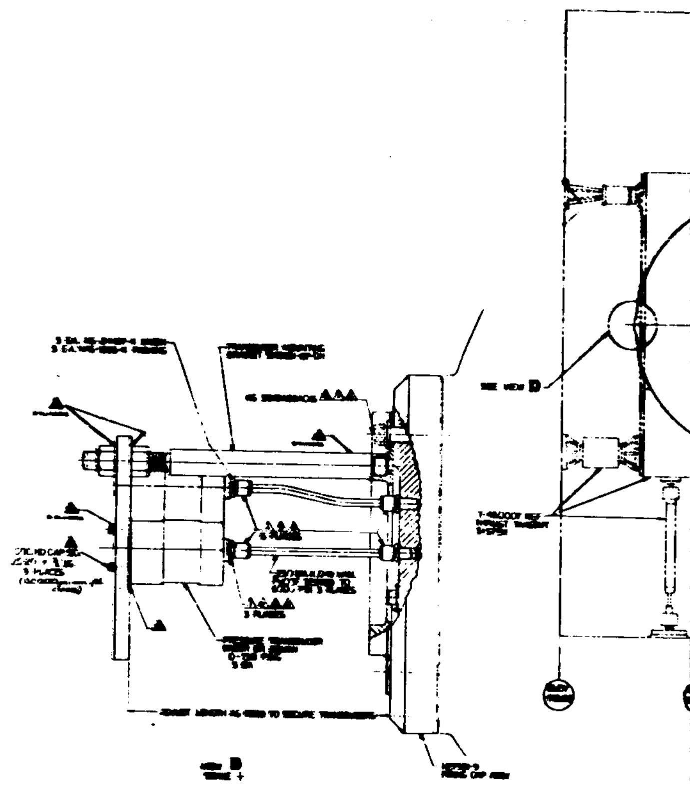
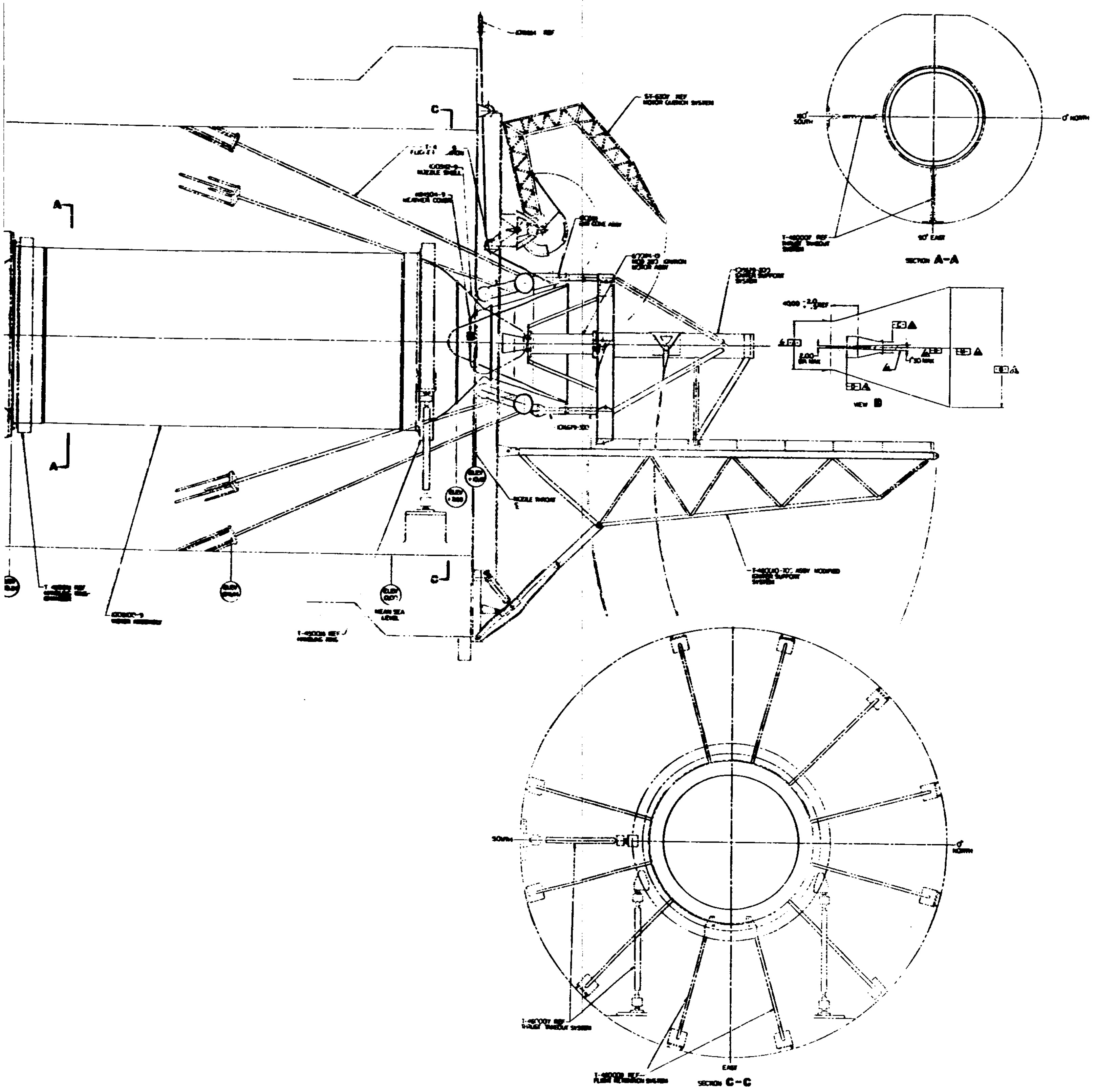
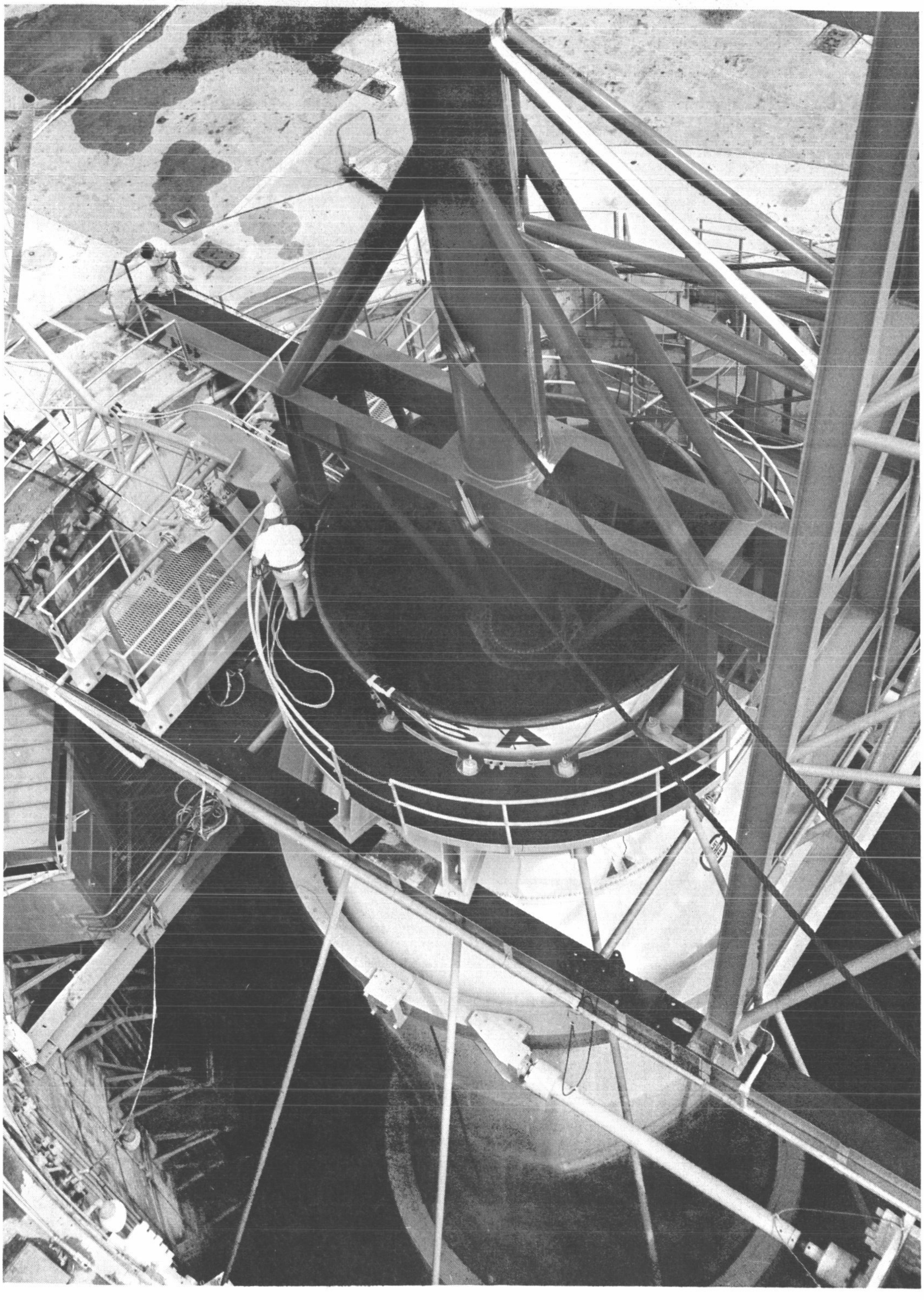


Fig 14-1



Motor Installation for Static Firing

Figure 14 — 2



Completed Motor Static Firing Installation

Figure 15

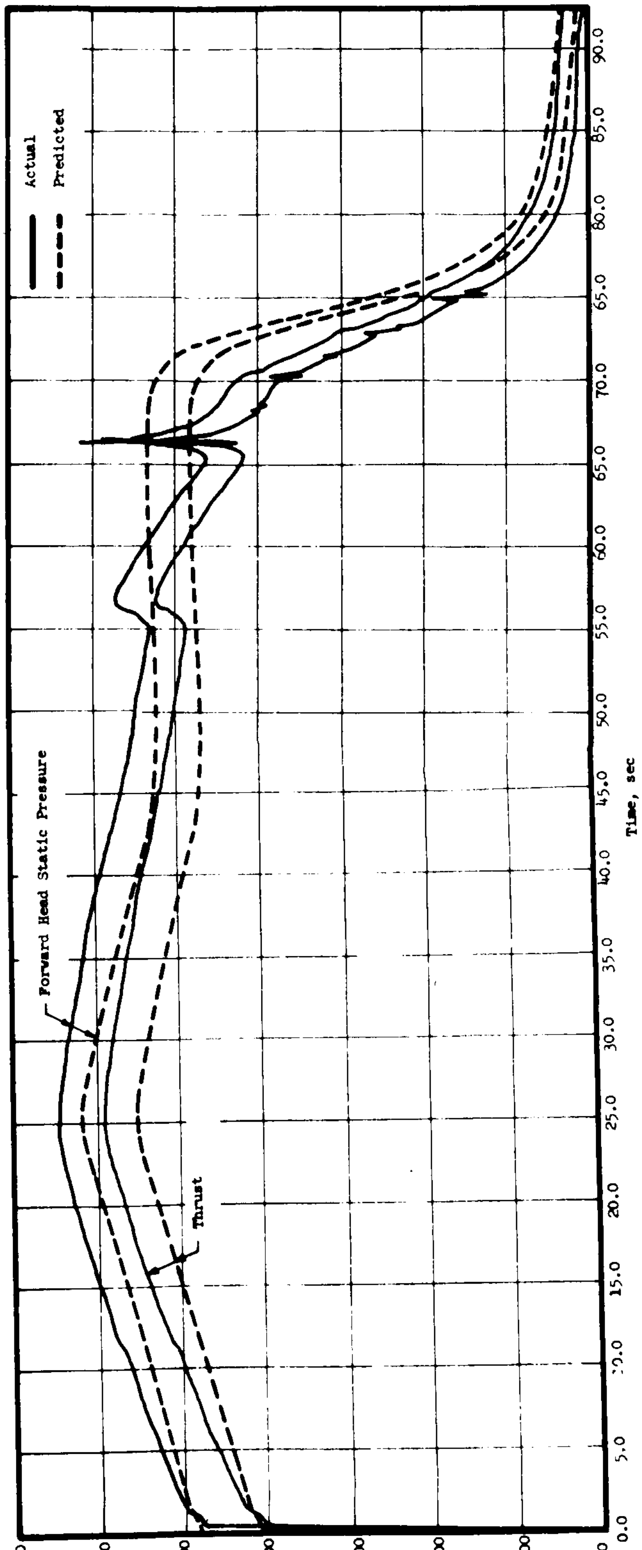
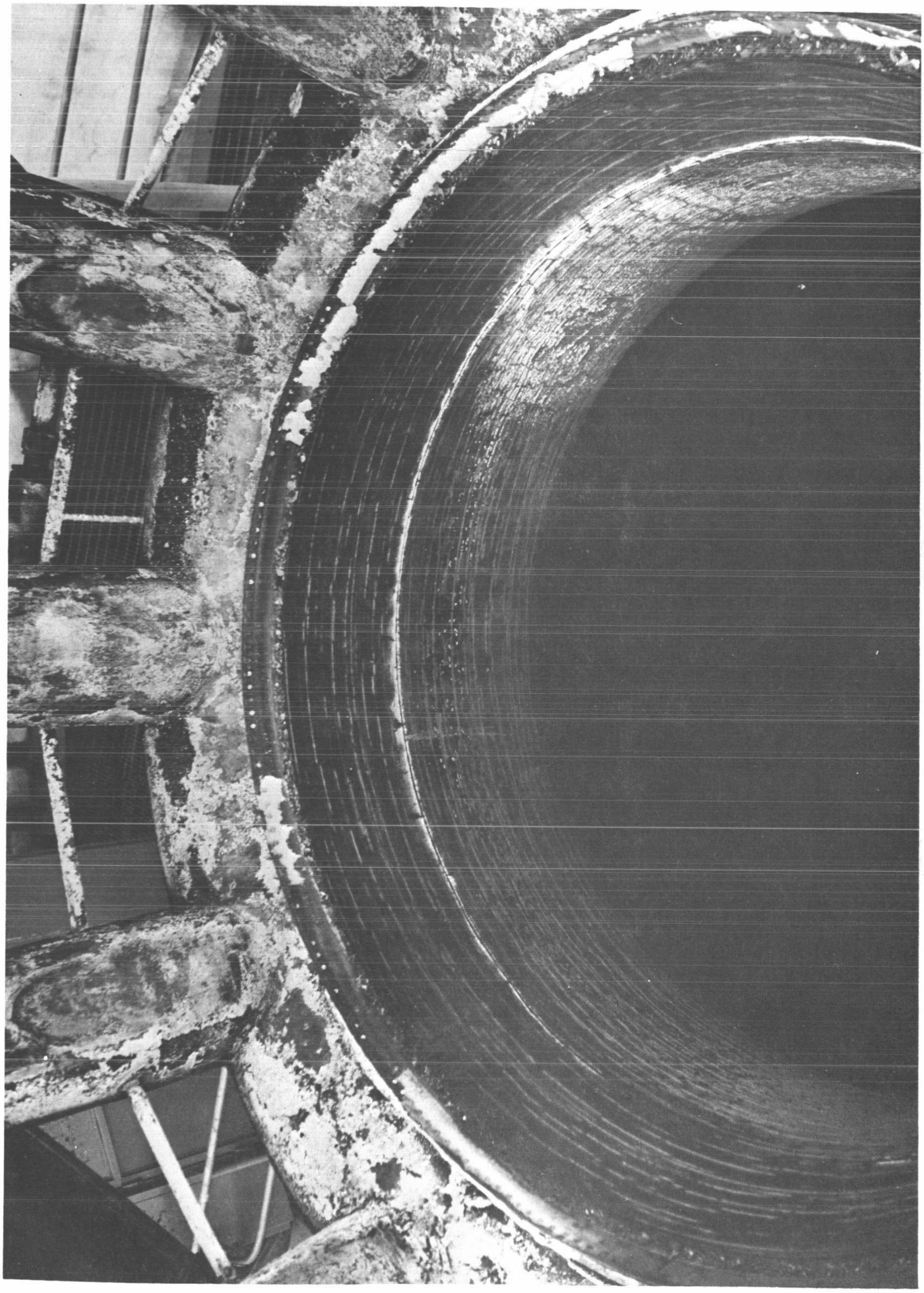


Figure 16

Pressure and Thrust-vs-Time Curves



Postfire View of Nozzle Throat Insert

Figure 17

260-SL-3 Quality Data File*

TABLE OF CONTENTS

* Quality Assurance Program Plan Motor 260-SL-3, paragraph 14.4, Quality Data.

APPENDIX

260-SL-3 QUALITY DATA FILE

VOLUME I - REHABILITATION OF CHAMBER

Section A Completed PAIS, IPR's, & QRR's for postfire operations.

Section B Completed PAIS, IPR's, & QRR's for chamber rehabilitation.

Section C Reports

1. Grit blast experiments to determine degree of metal reduction.
2. Nondestructive tests conducted during chamber rehabilitation.

VOLUME II - PREPARE FOR HYDROTEST, HYDROTEST, AND POST TEST

Section A Completed PAIS, IPR's, and QRR's covering preparation for hydrotest, hydrotest, and post test.

VOLUME III - REHABILITATION OF NOZZLE SHELL (SUN SHIPBUILDING & DRY DOCK COMPANY)

PART 1 - PROCURED ARTICLES

Section A Forging Acceptance - Nozzle Exit Section

1. A copy of the purchase order for the nozzle exit section forging.
2. Receiving inspection records that indicate acceptance to the purchase order and referenced specification requirements.
3. A list and a copy of each applicable completed nonconformance disposition, both internal and those submitted to Aerojet for approval.

Section B Forging Acceptance - Entrance Ring

A copy of the purchase order for the entrance ring forging.

2. Receiving inspection records that indicate acceptance to the purchase order and referenced specification requirements.
3. A list and a copy of each applicable completed nonconformance disposition, both internal and those submitted to Aerojet for approval.

Section C Weld Wire Acceptance

1. A copy of the purchase order for the weld wire.
2. Receiving inspection records that indicate acceptance to the purchase order and referenced specification requirements.
3. A list and a copy of each applicable completed nonconformance disposition, both internal and those submitted to Aerojet for approval.

PART 2 - RECEIVING INSPECTION AND PROCESSING OF AEROJET SUPPLIED SHELL - PN 600259-1S/N001

Section A Receiving Inspection of Aerojet Supplied Shell PN 600259-1S/N001

1. Inspection report of condition of shell as received.
   a. Visual dimensional inspection results.

Section B Processing of Shell, Parting, and Weld Preparation

1. A copy of the integrated planning for parting the nozzle shell, and weld edge preparation stamped by inspection to show acceptance.
2. Inspection records for the following:
   a. Dimensional inspection of entrance section.
   b. MPI records for entrance section and weld preparation.
   c. Radiography records for longitudinal welds and girth weld between cone and flange.

Section C — A list and copy of each applicable completed nonconformance disposition, both internal and those submitted to Aerojet for approval.

PART 3 - WELDING ENTRANCE SECTION AND EXIT FORGING AND MARAGING WELD SEAM (NOZZLE SHELL)

Section A — Welding Entrance Section and Exit Forging

1. A copy of the integrated planning for welding the two sections, stamped by inspection to show acceptance.
2. Inspection records for the following:
   a. Visual/dimensional inspection of weld.
   b. Radiographic report
   c. Ultrasonic report
   d. MPI report

Section B — Maraging Weld Seam

1. A copy of the integrated planning for maraging the weld, stamped by inspection to show acceptance.
2. A copy of the evaluation study results and procedures established for locally maraging the girth seam.
3. A copy of the evaluation study results and procedures for welding of maraged pieces.
4. A summary of the time/temperature trace for the maraging cycle stamped to show acceptance.

Section C — A list and copy of each applicable completed nonconformance disposition, both internal and those submitted to Aerojet for approval.

PART 4 - FINAL MACHINING AND INSPECTION NOZZLE SHELL AND ENTRANCE RING AND FIT UP

Section A Final Machining and Inspection, Nozzle Shell

1. Inspection records for the following:
   a. Dimensional inspection
   b. MPI records for machined exit flange

Section B Final Machining and Inspection, Entrance Ring

1. Inspection records for the following:
   a. Dimensional inspection
   b. MPI records for machined entrance ring.

Section C Fit Up

1. Inspection records showing results of inspection of the fit up of the nozzle shell and entrance ring.

Section D A list and copy of each applicable completed nonconformance disposition, both internal and those submitted to Aerojet for approval.

VOLUME IV - NOZZLE AND EXIT CONE FABRICATION AND ASSEMBLY (ROHR)

PART 1 - PROCURED ARTICLES

Section A Material Acceptance - Carbon/Phenolic, Silica/Phenolic, Glass/Phenolic Tapes and Broadgoods.

1. Material acquisition requirements per provisions of NPC 200-2, Para. 5.3.1., including numerical reference to the applicable purchase order document to assure traceability.
2. Receiving inspection records that indicate acceptance to the purchase order and referenced specification requirements.
3. Resample results as collected per the provisions of NPC 200-2, Para. 5.6 b., e., and f.

4. A copy of the certification for each lot and roll of the above tapes and broadgoods.

Section B — Exit Cone Ring Acceptance - PN 1005111-11 Ring (Exit Cone)

1. Material acquisition requirements per provisions of NPC 200-2, Para. 5.3.1, including numerical reference to the applicable purchase order document to assure traceability.
2. Receiving inspection records that indicate acceptance to the purchase order and referenced specification requirements.
3. Results of nondestructive tests required by Drawing 1005111 for the -11 ring.

Section C — Material Acceptance V-44 Rubber Stock

1. Material acquisition requirements per provisions of NPC 200-2, Para. 5.3.1, including numerical reference to the applicable purchase order document to assure traceability.
2. Receiving inspection records that indicate acceptance to the purchase order and referenced specification requirements.
3. Resample results as collected per the provisions of NPC 200-2, Para. 5.6.b., e., and f.

Section D — Miscellaneous

1. Material acquisition requirements per provisions of NPC 200-2, Para. 5.3.1, including numerical reference to the applicable purchase order document to assure traceability.
2. Receiving inspection records that indicate acceptance to the purchase order and referenced specification requirements.

Section E — A list and copy of any completed nonconformance report or SDAR, generated from procured articles. The list should reference the applicable section (A through D) generating the above record.

PART 2 - RECEIVING INSPECTION OF NOZZLE ENTRANCE RING, NOZZLE SHELL, AND EXIT CONE FLANGES

Section A

1. Receiving inspection records including any dimensional inspection performed to verify proper restraint of nozzle shell and entrance ring.
2. Receiving inspection records including any dimensional inspection performed on the Aerojet-supplied exit cone flanges.

Section B — A list and copy of any completed nonconformance report or SDAR, generated from receiving inspection of the above.

PART 3 - NOZZLE SHEL AND ENTRANCE INSULATION

Section A

1. A copy of the integrated planning for fabrication of the insulation stamped at each inspection point to indicate acceptance.
2. Inspection records including:
   a. Summary of charts from autographic recording of temperature, pressure, and vacuum versus time for the cure cycles.
   b. Variables data from final dimensional inspection.
   c. Results of nondestructive tests as specified by the applicable drawings.

Section B — A list and copy of any completed nonconformance reports and SDAR's generated from fabrication of the above.

PART 4 - THROAT EXTENSION FABRICATION

Section A Throat Extension (PN 1005113-1)

1. Manufacturing outline documents as specified in AGC-36413, Para. 3.8.2.
2. A copy of the integrated planning for fabrication of the component stamped off at each inspection point to indicate acceptance.
3. Inspection records including:
   a. Summary charts from autographic recording of temperature, pressure, vacuum versus time for the debulk and/or cure cycle.
   b. The actual as wrapped, preform debulk, and final cure exterior profiles of the billet .
   c. Physical and mechanical properties determined by testing specified in AGC-36413, Para. 3.9.
   d. Humidity and temperature ambients during wrapping.
   e. Results of nondestructive tests required by applicable drawings.

Section B A list and copy of each completed SDAR and internal non-conformance record generated by fabrication of this component.

PART 5 - THROAT INSERT FABRICATION

Section A Throat Insert (PN 1005115-3)

1. Manufacturing outline documents as specified in AGC-36413, Para. 3.8.2.
2. A copy of the integrated planning for fabrication of the component stamped off at each inspection point to indicate acceptance
3. Inspection records including:

a. Summary charts from autographic recording of temperature, pressure, vacuum versus time for the debulk and/or cure cycle.

b. The actual as wrapped, preform debulk, and final cure exterior profiles of the billet.

c. Physical and mechanical properties determined by testing specified in AGC-36413, Para. 3.9.

d. Humidity and temperature ambients during wrapping.

e. Results of nondestructive tests required by AGC-36413.

Section B A list and copy of each completed SDAR and internal nonconformance record generated by fabrication of this component.

PART 6 - SUBMERGED INSERT FABRICATION

Section A Submerged Insert (PN 1005115-21)

1. Manufacturing outline documents as specified in AGC-36413, Para. 3.8.2.
2. A copy of the integrated planning for fabrication of the component stamped off at each inspection point to indicate acceptance.
3. Inspection records including:

   a. Summary charts from autographic recording of temperature, pressure, vacuum versus time for the debulk and/or cure cycle.

   b. The actual as wrapped, preform debulk, and final cure exterior profiles of the billet.

   c. Physical and mechanical properties determined by testing specified in AGC-36412, Para. 3.9.

   d. Humidity and temperature ambients during wrapping.

e. Results of nondestructive tests required by applicable drawings.

Section B A list and copy of each completed SDAR and internal non-conformance record generated by fabrication of the above component.

PART 7 - NOSE INSERT FABRICATION

Section A Nose Insert (PN 1005115-11)

1. Manufacturing outline documents as specified in AGC-36413, Para. 3.8.2.
2. A copy of the integrated planning for fabrication of the component stamped off at each inspection point to indicate acceptance.
3. Inspection records including:
   a. Summary charts from autographing recording of temperature, pressure, vacuum versus time for the debulk and/or cure cycle.
   b. The actual as wrapped, preform debulk, and final cure exterior profiles of the billet.
   c. Physical and mechanical properties determined by testing specified in AGC-36412, Para. 3.9.
   d. Humidity and temperature ambients during wrapping.
   e. Results of nondestructive tests required by applicable drawings.

Section B A list and copy of each completed SDAR and internal non-conformance record generated by fabrication of the above component.

PART 8 - ENTRANCE INSERT FABRICATION

Section A Entrance Insert (PN 1005115-7)

1. Manufacturing outline documents as specified in AGC-36412, Para. 3.8.2.
2. A copy of the integrated planning for fabrication of the component stamped off at each inspection point to indicate acceptance.
3. Inspection records including:
    a. Summary charts from autographic recording of temperature, pressure, vacuum versus time for the debulk and/or cure cycle.
    b. The actual as wrapped, preform debulk, and final cure exterior profiles of the billet.
    c. Physical and mechanical properties determined by testing specified in AGC-36413, Para. 3.9.
    d. Humidity and temperature ambients during wrapping.
    e. Results of nondestructive tests required by applicable drawings.

Section B A list and copy of each completed SDAR and internal non-conformance record generated by fabrication of the above component.

PART 9 - EXIT CONE FABRICATION

Section A Exit Cone Liner (PN 1005111-7)

1. Manufacturing outline documents as specified in AGC-36413, Para. 3.8.2.
2. A copy of the integrated planning for fabrication of the component stamped at each inspection point to indicate acceptance.
3. Inspection records including:

a. Summary charts from autographic recording of temperature, pressure, and vacuum versus time for the debulk and/or cure cycle.
b. The actual as wrapped, preform debulk and final cure exterior profiles of the billet.
c. Physical and mechanical properties determined by testing specified in AGC-36413, Para. 3.9.
d. Humidity and temperature ambients during wrapping.
e. Results of nondestructive tests required by applicable drawings.

<u>Section B</u> Exit Cone Flanges Modification

1. A copy of the integrated planning for machining and sub-assembly of the exit cone flanges per Drawing 1005111 stamped at each inspection point to indicate acceptance.
2. Inspection records including:
   a. Dimensional inspection as required by AGC-36498, Para. 3.1.
   b. Nondestructive tests of final machined assembly per Drawing 1005111.

<u>Section C</u> A list and copy of each completed nonconformance report and SDAR generated by fabrication of the above component.

PART 10 - PARTS ASSEMBLY - NOZZLE

<u>Section A</u> Nozzle Entrance Assembly (PN 1005115-9)

1. A copy of the integrated planning for assembling inserts and entrance insulation to the nozzle entrance ring stamped at each inspection point to indicate acceptance.
2. Inspection records including:

a. Results of all nondestructive tests required by applicable drawings and specifications.
b. Recording of temperature and pressure versus time during cure cycles.
c. Physical and mechanical properties determined by testing specified in AGC-36497, Para. 4.5.

Section B Nozzle Shell Assembly (PN 1005113-9)

1. A copy of the integrated planning for assembling throat extention insert to the nozzle shell stamped at each inspection point to indicate acceptance.
2. Inspection records including:
   a. Results of all nondestructive tests required by applicable drawings and specifications.
   b. Recording of temperature and pressure versus time during cure cycles.
   c. Physical and mechanical properties determined by testing specified in AGC-36497, Para. 4.5.

Section C Nozzle Entrance and Shell Assembly (PN 1005117-9)

1. A copy of the integrated planning for the assembly operations stamped off at each inspection point to indicate acceptance.
2. Inspection records including results of tests required by drawings and specifications.

Section D A list and copy of each completed SDAR and internal nonconformance record generated by the assembly of the above.

PART 11 - PARTS ASSEMBLY - EXIT CONE

Section A Exit Cone Flanges Assembly

1. A copy of the integrated planning for assembly of the

exit cone flanges stamped at each inspection point to indicate acceptance.

2. Inspection records including:
   a. Dimensional inspection per Drawing 1005111-9 for the flange rings assembly.
   b. Cure cycle for bonding per AGC-36498, Para. 3.4.
   c. Nondestructive test of bond per AGC-36498, Para. 3.6.
   d. Test panel testing results per AGC-36498, Para. 4.6.

Section B Glass Structural Wrap

1. A copy of the integrated planning for wrapping the assembly stamped at each inspection point to indicate acceptance. The above is to contain material used information and wrapping conditions.
2. Manufacturing outline documents as specified in AGC-36496, Para. 3.9.2.
3. The physical and mechanical properties determined by testing specified in AGC-36496, Para. 3.8.
4. A summary of actual pressure and temperature cycles employed during the curing operation.

Section C Exit Cone Testing

1. A copy of the integrated planning for required tests stamped at each inspection point to indicate acceptance.
2. Inspection records including:
   a. Results of leak test specified in AGC-36498, Para. 3.10.
   b. Results of ultrasonic tests specified in AGC-36498, Para. 3.12.2.

Section D A list and copy of each completed SDAR and internal nonconformance report generated by the assembly of the above.

PART 12 - FINAL MACHINING AND INSPECTION, FIT-UP, PREPARATION FOR SHIPMENT

Section A Final Machining and Inspection

1. A copy of the integrated planning for the final machining of the nozzle and entrance assemblies stamped at each inspection point to indicate acceptance.
2. Inspection records including:
   Variables data as required by Drawing 1005117-9.

Section B Fit-up between Nozzle and Exit Cone

A copy of the integrated planning for the fit check between nozzle and exit cone stamped by inspection to indicate acceptance.

Section C Preparation for Shipment

A copy of the integrated planning for preparation for shipment of the nozzle and exit cone stamped by inspection to indicate acceptance.

Section D A list and copy of all SDAR's and internal nonconformance reports generated by the above.

VOLUME V - CHAMBER INSULATION (GOODYEAR)

PART 1 - RAW MATERIALS

Section A A copy of the purchase order for the material, including Quality Assurance provisions

Section B Receiving inspection records for the material, showing acceptance criteria and evidence of acceptance.

Section C A copy of the Certification of Conformance from the material supplier.

Section D A copy of each completed nonconformance dispositioned, both internal and SDARs covering raw material.

PART 2 - INSULATION COMPONENTS - FORWARD BOOT

Section A A copy of the integrated planning for fabricating the forward boot segments, showing evidence of inspection acceptance, records of dimensional inspection, a summary of the cure cycle(s), and evidence of use of acceptable raw materials.

Section B A copy of each nonconformance sispositioned, both internal and SDARs.

PART 3 - INSULATION COMPONENTS - CENTER SECTIONS

Section A A copy of the integrated planning for fabricating the center section segments, showing evidence of inspection acceptance, records of dimensional inspection, a summary of the cure cycle(s), and evidence of use of acceptable raw materials.

Section B A copy of each nonconformance dispositioned both internal and SDARs, covering center section fabrication.

PART 4 - INSULATION COMPONENTS - AFT BOOT

Section A A copy of the integrated planning for fabricating the aft boot segments, showing evidence of inspection acceptance records of dimensional inspection, a summary of the cure cycle(s), and evidence of use of acceptable raw materials.

Section B A copy of each nonconformance dispositioned, both internal and SDARs, covering aft boot fabrication.

PART 5 - CAP ASSEMBLY, INSULATED

Section A — A copy of the integrated planning for fabricating the forward cap insulation and assembly with the forward cap, showing evidence of inspection acceptance records of dimensional inspection, a summary of the cure cycle(s) and evidence of use of acceptable raw materials.

Section B — Receiving inspection records showing acceptance of forward cap, supplied by Aerojet.

Section C — A copy of each nonconformance dispositioned, both internal and SDARs, covering forward cap insulation fabrication and assembly.

The Quality Control documentation shall be submitted incrementally as each Log Book Volume is completed.

The place of acceptance of the materials purchased will be the supplier's facility.

VOLUME VI - INSTALLATION OF INSULATION

Section A — Receiving Inspection Records for Chamber Insulation Completed PAIS, IPR's and QRR's covering installation of chamber insualtion.

Section B — Engineering Evaluation of Ram Merial and Installed Insulation

VOLUME VII - PROPELLANT/LINER PROCESSING AND MOTOR LOADING OPERATIONS

Section A — Copy of completed integrated planning segments (PAIS, IPR's, and QRR's).

1. Inert sliver mix, cast, cure and installation.
2. Prepare liner, line and weigh chamber.
3. Assemble for cast; prepare and install core.

4. Prepare oxidizer, fuel, and mix propellant.

VOLUME VIII - PROPELLANT CAST AND CURE

Section A Copy of completed Integrated Planning Segments (PAIS), IPR's, and QRR's for propellant casting.

Section B Copy of completed Integrated Planning Segments (PAIS), IPR's, and QRR's covering the following:

1. Cure propellant
2. Sample properties
3. Remove core and weigh motor (untrimmed)
4. Pot and trim boot, restrict grain
5. Weight Report - trimmed motor (untrimmed motor weight less weight of propellant trimmings)
6. Engineering evaluation of cast, cure, cool, core removal, weight and trim operations, including mechanical properties and ballistic data.

VOLUME IX - IGNITION SYSTEM FABRICATION AND PROPELLANT CAST

Section A Igniter Motor Hardware Fabrication and Processing

1. Dimensional inspection, MPI and X-ray results of rehabilitated motor assembly.
2. Hydrotest igniter motor test plan and test referral.
3. Receiving inspection records for receipt of insulated igniter chamber, throat insert, and exit cone.
4. Copy of completed integrated planning (PAIS) used in processing and assembly operations.
5. Copy of each completed nonconformance disposition generated in above processing.

6. Engineering evaluation of ignition motor, including summary of propellant data, such as laboratory test results, liquid stand burning rates, and mechanical properties.

Section B Propellant Processing and Casting

1. Copies of completed Integrated Planning used in propellant processing and installation.
2. List of IR's generated during cast and installation.
3. Acceptability of safe/arm and igniter assembly.

VOLUME X - FINAL MOTOR ASSEMBLY

Section A Final Motor Assembly

1. Receiving and certification of O-ring and related sealants, nozzle assembly, and bolt assemblies.
2. Copies of PAIS's and IPR's covering O-ring installation, sealant application, nozzle, exit cone and bolt torquing, and leak check.
3. Copies of each QRR generated.

VOLUME XI - TEST OPERATIONS AND ENVIRONMENTAL HISTORY (CHAMBER AND MOTOR) (INCLUDES IGNITER - SAFE ARM ASSEMBLY AND IGNITER MOTOR INSTALLATION)

Section A Test Operations

1. Copy of all completed Integrated Planning (PAIS) and IPR's.
2. Copy of each test request and supplement.
3. Copy of each QRR generated during test operation.

VOLUME XII - <u>POST FIRE DISASSEMBLY AND ANALYSIS</u>

<u>Section A</u> Post Disassembly

Copy of all completed integrated planning (PAIS) and IPR's.

<u>Section B</u> Post Fire Analysis

Post fire quality analysis including condition of motor and components after firing and any additions or deletions from planned operations.